THE

JOURNAL OF GEOLOGY

SEPTEMBER–OCTOBER, 1898

GEOLOGY OF A PORTION OF THE SOUTHERN COAST RANGES.[1]

CONTENTS.

Introduction.
Topographical features.
Sedimentary terranes.
  Jurassic period.
    Golden Gate series.
  Cretaceous period.
    Knoxville beds.
    Chico formation.
  Tertiary period.
    Neocene.
      Monterey series (Lower Neocene).
      San Pablo formation (Middle Neocene).
      Paso Robles formation (Upper Neocene).
  Pleistocene.
Igneous rocks.
Structural geology.
Geological history.

INTRODUCTION.

It is the intention to present in the following paper a résumé of the most important results obtained during a detailed study of a portion of the southern Coast Ranges of California.

The area embraces about 570 square miles in the western part of San Luis Obispo county with the town of the same name nearly in the center. It has a length from north to south of thirty-five miles and an extreme width from east to west of

[1] Published by permission of the director of the United States Geological Survey.

twenty-nine miles. The seacoast traverses it diagonally forming the southwest boundary. The region is one of complex structural features and has represented within it nearly all the sedimentary formations characteristic of the Coast Ranges as well as a great variety of igneous rocks. As far as the writer has yet studied the Coast Ranges no other region of equal area has been found to contain so much of geologic interest.

More than six months of the past year has been devoted to field work[1] in this region besides several reconnoissances in former years. It is expected that a part of the results will appear in the form of a folio of the United States Geological Survey, and a complete report later in one of the Annuals.

TOPOGRAPHIC FEATURES.

The main topographic features have a northwesterly and southeasterly direction. The Santa Lucia is the highest and most important mountain range, extending parallel with the coast across the center of the area surveyed. On the south forming the high ridge terminating on the ocean in Point Buchon is the San Luis range. Crossing the northeast corner of the area is the northern extension of the San Jose range. All three ranges are traversed by narrow canyons which open upon broad and almost level or undulating valleys which extend in a northwest and southeast direction between these three important mountain blocks. The area is thus divided into two portions with sharply contrasted cycles of development, that is, recent mountain ranges with steep slopes and traversed by narrow canyons, and broad valleys in an advanced stage of base-leveling.

The Santa Lucia range forms the divide between those streams which flow directly into the Pacific Ocean and those which drain into the Salinas River. The valley of the upper portion of this river crosses the region surveyed between the

[1] The writer was aided in the field by Mr. F. E. Harvey, a senior student in Stanford University, and Mr. Robert Moran of San Luis Obispo, both enthusiastic students.

Santa Lucia and San Jose ranges. South of the Santa Lucia, between it and the San Luis range, are the broad and fertile San Luis and Los Osos valleys opening northwestward to Morro Bay. A series of sharp peaks extends from a point a little south of the town of San Luis Obispo northwest to Morro Rock separating these valleys from the foothills of the Santa Lucia range.

The Santa Lucia range as far as its recent movements are concerned forms a geological unit, and viewed from the south it presents a bold and comparatively regular front and even sky line. The highest portion has an elevation of nearly 3000 feet, and the summit a width of two to four miles. The topography of this range while presenting certain common features yet varies greatly in different portions, owing to the marked variation in resistency offered to erosion by the different geological formations. The Monterey shales, which are mostly confined to that portion east of Cuesta Pass, are cut by deep V-shaped canyons while northwest of this pass the soft Knoxville shales, extending longitudinally through the centre of the range, exhibit a succession of open valleys.

The granite mountains (San Jose range) in the northeastern corner of the area surveyed reach an elevation of nearly 2000 feet, but do not seem so high because of the elevated valleys about them. They are cut by narrow canyons, but do not rise as abruptly from the adjoining valleys as the Santa Lucia range. This elevation of land is a magnificent example of an ancient base leveled mountain range. Viewed from most any point along the foothills of the Santa Lucia range the numerous furrowed ridges fall into an even sky line many miles long.

The San Luis range attains an elevation of a little over 1800 feet. It consists of a series of sharp ridges traversed by deep narrow canyons. To the east it lessens in height and finally blends with the Santa Lucia range.

The line of buttes extending from the vicinity of San Luis Obispo northwestward and terminating in Morro Rock constitutes the most remarkable scenic feature in the landscape. The buttes

rise from 400 to 1500 feet from open valleys which are but little elevated above tide level, and terminate in Morro Rock which rises out of the ocean to a height of nearly 600 feet. These are undoubtedly peaks of erosion, the hard crystalline rock of which they are composed weathering away much more slowly than the soft strata of the Golden Gate series in which they were intruded.

The extensive valleys south of the Santa Lucia range are underlaid by the oldest sedimentary rocks (Golden Gate series) of the sheet and are, in their general features, of great antiquity compared with the abrupt mountain ranges on either hand. The valley block has acted practically as a unit since the period of disturbance giving rise to the Santa Lucia and Buchon ranges.

The principal hydrographic basin is that of the Salinas. This stream flowing across the northeast corner of the area pursues a comparatively regular course until it empties into Monterey Bay. The remarkable thing, however, about the river is, that instead of flowing in the lowest depression between the Santa Lucia range and the granite mountains, it has cut a channel for a number of miles through the granite flowing in a canyon 500 to 700 feet deep.[1] Its meandering course brings it in places to the edge of the granite, where it receives tributary streams from the Santa Lucia. These transverse streams have so eroded their separating divides in the soft sandstones between the two ranges that they form an almost continuous valley which is strictly a continuation of the valley of the Salinas farther down. This is clearly a case of superimposed drainage, for when the course of the Salinas and its tributaries was originally outlined the present valley region must have been higher than the granite ridge.

A similar superimposed drainage is to be observed in the case of the streams which flow southwesterly from the Santa Lucia range. These traverse the broad open stretches of the San Luis valley, which in its lower portion is not over 200 feet

[1] JOUR. GEOL., Vol. V, p. 576.

above the sea, and separated from Los Osos valley by a divide not 50 feet high, and then pass directly into the San Luis range, cutting across it in narrow canyons at right angles to its course for a distance of over three miles. The most westerly of these streams, the San Luis Creek, has cut through where the range is 1000 feet high; and the other, Pismo Creek, traverses it where it is but little lower. The watershed between these streams has almost disappeared, and but little change in the topography would cause the whole drainage to pass westward along the northern slope of the San Luis range to Morro Bay. When the courses of these streams were originally outlined the San Luis range probably did not exist, and the general slope of the country was southwesterly. With the beginning of the upward movement along the axis of the range erosion continued to be rapid enough so that the original drainage was maintained.

SEDIMENTARY TERRANES.

An almost continuous series of sediments from the Middle Mesozoic down to the present is represented in different portions of the central and southern Coast Ranges, but owing to the oft repeated mountain-making disturbances the series is not complete at any one spot. Except for the absence of the Horsetown beds, the Eocene, and possibly the marine Pliocene, the series is practically complete in the region under discussion.

In the northern portion of the Santa Lucia range and other portions of the Coast Ranges there is still an older series of sedimentary rocks which are of unknown age, but were involved in the granite magma at the time of its formation and now appear as marbles, schists, etc. All that is known about these rocks is that they are older than the granite, and that the granite itself is much older than the Golden Gate series (Jurassic) which rests upon it with a basal conglomerate. None of these metamorphic rocks appear associated with the granite north of the upper Salinas River, although farther northwest along the same crystalline axis they are extensively developed.

JURASSIC PERIOD.

Golden Gate series. — This series forms the base of the unaltered sedimentary rocks in the central and southern Coast Ranges. The exact position of these rocks in the geologic scale remained a puzzle to geologists for many years, partly because of the scarcity of fossils, and partly because of the obscure stratigraphic relations.

In former papers[1] the writer has advanced considerations for the belief in the pre-Cretaceous age of this series of rocks, and that it underlies the Knoxville unconformably. In later papers[2] the series was named and more definite proofs given of its relation to the Knoxville. During the recent detailed study of the region about San Luis Obispo the question was conclusively settled in favor of the position maintained by the writer. Two lines of evidence aided in the determination. The first concerns the relation of the series to the Knoxville. Both of these groups of rocks are extensively developed in the region in question, each with its characteristic features. The Golden Gate series is most largely exposed along the southern slope of the Santa Lucia range, in the large valleys at its base, and on the northern slope of the San Luis range. A narrow strip also occurs on the northern side of the Santa Lucia range, exposed through faulting. The Knoxville beds begin as scattered outcrops on the southern slope of the Santa Lucia range east of the town of San Luis Obispo and extending northwest through the depression in the range known as Cuesta Pass, expand to form many square miles of mountainous country through the heart of the range. At numerous points on the northern slope of the range, from the Eagle Ranch to the head of Morro Creek, were found patches of the basal Knoxville conglomerate, either resting upon the upturned Golden Gate series, or upturned itself and faulted down into the latter series. Specimens of Aucelia were found in strata of sandstone and fine conglomerate within four feet of

[1] Am. Geol., Vol. IX, p. 153; Am. Geol., Vol. XI, p. 70; Bull. Geol. Soc. Am., Vol. VI, p. 71.

[2] Jour. Geol., Vol. III, p. 415; Am. Geol., Vol. XVIII, p. 350.

the base of the beds. Near the road, two miles northeast of San Louis Obispo, the base of the Knoxville beds is exposed on a little hill. It consists of conglomerate, perhaps thirty feet thick, and dips easterly at a low angle. Exposed on either side of the hill and passing through under the conglomerate is one of the pre-Cretaceous basic intrusives similar to others near by in the Golden Gate series. This must have been the old sea bottom on which the conglomerate was deposited. In Reservoir Canyon, a little more than a mile southeast of this locality, is a hill about one-half mile in diameter formed of Knoxville shales and one thin layer of conglomerate. The shales are but little inclined and are underlaid and surrounded on all sides by the upturned and nearly vertical sandstones and associated intrusives of the Golden Gate series. Perfectly preserved specimens of *Aucella* were obtained from a concretionary nodule at the very base of the Knoxville on the south side of the hill.

The second line of evidence, that of palæontology, leads to the conclusion that the series is not older than the Jurassic, the radiolaria as well as the molluscan remains both agreeing upon this point. All the specimens of the latter so far obtained from the series are probably new species and appear to be indeterminate as far as the question of Jurassic or Cretaceous age is concerned. Only one locality of mulluscan fossils was discovered and that is located on the coast, six miles north of Port Harford. A small species of a pecten-like form occurs in great abundance here through a thickness of about eighty feet of black slate which stands vertical and is inclosed between dikes of diabase.

The strata of the Golden Gate series consist of sandstone which forms fully four-fifths of the whole, numerous lenticular beds of radiolarian jasper, shale, and a little conglomerate. The whole has been upturned, folded, and faulted in a very complex manner and intruded at various periods by dikes of igneous rocks in great variety and abundance. The different members of this series have the same character as in other portions of the Coast Ranges where they have been described.[1]

[1] Bull. Geol. Soc. of Am., Vol. VI, p. 82; U. S. Geol. Sur., XVth Annual Report, p. 415.

The sandstone is characteristically thick bedded and in general shows little if any metamorphism, except in the vicinity of eruptive masses. It disintegrates readily, forming a rather heavy soil. It is almost everywhere, however, seamed and fissured, while the softer, shaly strata are often crushed and distorted. The five-mile section along the coast, north of Port Harford, exhibits the relative proportion of sandstone in the series. Along this stretch the strata stand vertical and with the exception of thin layers of shale and several lenticular strata of jasper consists entirely of sandstone. The apparent thickness of this section is fully 10,000 feet, but whether this represents the total thickness of the Golden Gate series is not certain.

The outcrops of jasper are very abundant over the whole of the region occupied by the Golden Gate series, and as they weather away much more slowly than the sandstones form the most prominent of the smaller topographic features, rising often as jagged or rounded knobs above the rolling contour of the hills. There are at least half a dozen important horizons, which, though apparently not confined to any one portion of the series yet are mostly aggregated toward what seems to be the basal portion. The strata of jasper are of very irregular dimensions swelling and pinching and often appearing as isolated lenses, but rarely exceeding 100 feet in thickness. The basic intrusives so numerous in the Golden Gate series occur mostly in that portion occupied by the jasper beds, the latter generally being reddened and often involved in the erupted masses. The contact of the jasper with the sandstone as well as the easy parting of the jasper bands undoubtedly facilitated the passage of the molten matter. The organic nature of the rock is indicated by the minute radiolarian skeletons in which the structure can often be seen with a pocket lense.

Scattered over the area occupied by the Golden Gate series occur prominent outcrops of a metamorphic schistose rock having a predominantly bluish tint. Owing to the general covering of soil the relations of these rocks are not always shown but where exposures are sufficiently good they appear to

be bunch-like or eliptical in form, sometimes 100 feet thick and several hundred feet long, and from this size down to those only a few inches in thickness. Where the inclosing rocks are exposed they invariably lie in contact with one of the fine grained basaltic intrusives. Glaucophane gives the characteristic bluish tint, but other minerals, such as a pearly mica, chlorite, quartz and garnet occur. These rocks possess great interest though the problems connected with their occurrence are not yet all solved. There can be little question that they have been formed through the metamorphosis of argillaceous strata in contact with igneous masses, but why this action was so irregular and intermittant it is difficult to comprehend. It is also puzzling to know why the contact rocks are invariably associated with a certain type of the pre-Cretaceous basic intrusives and not with others, such as the peridotites. The exceeding abundance of the contact rocks through those areas of the Golden Gate series where the old eruptives are the most numerous, indicates plainly that the most if not all the latter are of subsequent origin.

CRETACEOUS PERIOD.

Knoxville Beds.—The rocks of lower Cretaceous age are now confined to the Santa Lucia range, although once probably much more extensive. They form an almost continuous strip from the head of the Corral de Piedra Creek on the south slope of the Santa Lucia range northwest for a distance of over twenty miles. North of Cuesta Pass they widen out forming for a number of miles nearly the whole of the brush-covered mountains between the two crests of the range. The structure of this portion is synclinal and seems to be due to the intrusion of great masses of diabase along its edges and which form the double crests referred to. The beds are perhaps 3000 feet thick and consist of dark shales and thin bedded sandstones closely resembling those of the same age in other parts of the state. Several thin layers of pebbly conglomerate occur, one being at the base and containing numerous pebbles of jasper and other silicious rocks.

The genus *Aucella* is well represented through the lower and middle portion of the shales, but the upper portion appears to be barren of life.

The nonconformity with the underlying Golden Gate series is most marked, not only by the discordance in dip but through much less distortion of the upper beds and the entire absence of the intrusives so characteristic of the lower series. Although so much evidence exists of a break between these two groups of rocks, its real magnitude does not yet seem to be appreciated by geologists as it ought. The more the question is studied the more its importance must appeal to geologists.

Chico formation.— The upper portion of the Shasta group known as the Horsetown beds was not recognized within the area under discussion and it seems probable from the stratigraphic relations existing between the Knoxville beds and the Chico formation that it is absent. The Chico occurs in two widely separated localities. The most important one forms a belt one to two miles wide and many miles long on the northern slope of the Santa Lucia range. The other is a strip about the same width extending along the coast from a point six miles west of Cayucos, northwestward for about eighteen miles. In both areas the rock consists almost wholly of sandstone. Fossils are not abundant but they were found in sufficient numbers in the Santa Lucia Mountains to demonstrate the age of the formation. In the latter locality the sandstone terminates downward in a conglomerate which is in places 100 feet thick, resting either upon the Knoxville shales or the Golden Gate series. The sandstones on the coast rest upon the Golden Gate series exclusively. The relation to the Knoxville shales was carefully examined at many points along the northern slope of the Santa Lucia Mountains and a conclusion reached which is in accord with one already published,[1] namely, that the lower and upper Cretaceous are, in this region at least, separated by a nonconformity. This is shown by the marked discordance in the dip between the two and the extension of the upper across the

[1] JOUR. GEOL., Vol. III, p. 426.

strike of the lower, as well as by the fact that the upper rests indiscriminately upon either the lower Cretaceous or the Golden Gate series. A nonconformity is also indicated by the fact that where the serpentine in this region, as in other portions of the Coast Ranges, comes in contact with the lower Cretaceous, the relation is one of intrusion while the Chico rests upon it undisturbed. The lower Cretaceous was intruded by the peridotite, upturned and eroded before the deposition of the Chico.

TERTIARY PERIOD.

Strata of Middle Tertiary age are widely distributed over this region and probably once covered nearly the whole of it. The Eocene on the contrary is entirely absent although extensively developed to the southeast in Santa Barbara and Ventura counties. It seems probable that during early Tertiary time this portion of the Coast Ranges was above water for if the Eocene ever had existed here it would be reasonable to expect some remnant of it would be met with. The Lower, Middle, and Upper Neocene are all represented.

NEOCENE.

Monterey series (*Lower Neocene*).—With the beginning of the Neocene a subsidance commenced and continued through, or nearly through the Miocene. Finally, almost the whole Coast Range region was submerged and a thickness of rocks in many places of more than 7000 feet was deposited. The most characteristic feature of the series is the bituminous shales. They form its upper portion and reach a thickness of 5000 feet. Below them are limestones, clays, volcanic ash, sandstones and conglomerates. Erosion has removed a large part of these rocks, but the similarity in succession of the characteristic horizons at various points in the area surveyed points to the fact of their former continuity.

The sandstones and conglomerates at the bottom of the series are most prominently developed in the region lying east of the Rinconada Valley, between it and the main granite range.

The thickness of these beds is remarkable, being 6000 to 8000 feet. They occupy the same position with reference to the bituminous shales as similar beds on the upper San Antonio River.

The volcanic ash forms a fairly constant horizon over nearly the whole of the region mapped. Several different centers of volcanic action seem to have existed in this region shortly after the beginning of the Miocene. In the mountains south of San Luis Obispo the ash has a thickness of fully 800 feet, while beginning near the Lion rock at the western end of the San Luis range this bed of volcanic ash extends easterly along the southern slope for a distance of over thirty miles. Near the centers of eruption the fragments are coarse, but farther away the deposit consists of frothy pumice, and in places occurring in beds of glass as fine as dust. On Old creek a small flow of banded rhyolite is associated with the fragmental material. It seems probable from the large amount of ash and small amount of massive lava that the eruptions were of an explosive nature and took place at or beneath the surface of the sea. This is the same eruption as that indicated at Point Sal.[1]

The bituminous shales and flints form the uppermost member of the Monterey series. They constitute the main portion of the San Luis range and that portion of the Santa Lucia range lying east of Cuesta Pass. They also underlie the younger formations in the upper Salinas Valley. This formation measured in both ranges appears to reach the enormous thickness of 5000 feet. It consists almost exclusively of a thin banded silicious shale which over extensive areas has been changed to a flint. Much remains to be done in a detailed study of these shales, although it has been quite certainly proved that they are largely of organic origin.[2] The shales are generally more or less impregnated with bituminous matter, and it appears to be reasonably certain that they constitute the main source of the oil and asphaltum which is so widely distributed through the Coast Ranges. Springs of thick oil and sulphurous water issue from

[1] Bull. Dept. of Geol., University of California, Vol. II, p. 16.

[2] Bull. Dept. of Geol., University of California, Vol. II, p. 13.

them, and when covered by porous beds vast deposits of bitumen have been formed.

San Pablo formation (*Middle Neocene*).—Overlying the Monterey series unconformably is a series of soft sandstones, diato-

Nonconformity between the San Pablo formation and the Monterey series. Ocean cliffs near Pismo.

maceous beds, and some flinty shales. It forms the eastern extension of the San Luis range between San Luis Obispo and the ocean, as well as a considerable area in the upper Salinas Valley. In the latter region it is filled with fossils which indicate the Middle Neocene, but to be more exact, whether the uppermost Miocene or the lowest Pliocene is as yet undetermined. Dr. Merriam has in a recent publication[1] described a series of strata on the southern shore of San Pablo Bay containing a similar fauna which he believes represents a distinct and

[1] Bull. Dept. of Geol., University of California, Vol. II, No. 4.

hitherto unrecognized palæontologic group. These strata it appears overlie those of the Contra Costa county Miocene with indications of a nonconformity, but the fossils collected from them by earlier palæontologists have in some cases been referred to the Miocene, in others to the Pliocene. To this series of rocks Dr. Merriam has given the name San Pablo formation. As the group of rocks in the southern Coast Ranges is undoubtedly the equivalent of those on San Pablo Bay, the latter name will be extended to it. In the San Luis Obispo region the nonconformity of this series of rocks with the Monterey series is distinctly shown in many places. Good examples appear along the coast north of Pismo as well as in the vicinity of Santa Margarita in the upper Salinas Valley. The basal conglomerates of the San Pablo formation, often but little disturbed, lap over on the more highly tilted and disturbed shales and contain many fragments of the latter often filled with mollusk borings. A great interval of time must have separated the deposition of the San Pablo formation from that of the bituminous shales, for the former formation extends over the shales in places and rests directly on the Golden Gate series. This time must have been sufficient for the erosion of at least 5000 feet of the Monterey series. During this time also the chief chemical change was wrought in the bituminous shales, for pebbles of the flinty altered shales occur at the base of the San Pablo formation in exactly the same condition as the shales on which this formation rests.

The discovery by Dr. Merriam of the marked palæontologic differentiation of the fauna of this group of rocks is an important addition to our knowledge of the younger formations of the Coast Ranges. That it is not a local condition is shown by the results reached by the writer along different lines and wholly independently. The pronounced nonconformity so clearly apparent in the San Luis Obispo region is confirmatory of the palæontologic investigations and firmly establishes the validity of the new formation. Its fauna is certainly older than that of the Merced beds, and if it should prove to be the upper-

most Miocene the rocks of that age in California can no longer be looked upon as forming a unit but separated into two divisions by an extended period of elevation and erosion. This point established other and puzzling questions relating to the Miocene and Pliocene are in a fair way to be cleared up.

Paso Robles formation.—The later Neocene in this portion of the Coast Ranges consists of a very extensive series of beds having apparently a fresh-water origin. They fill the Salinas Valley as far up as Atascadero, lapping over unconformably upon the upturned and sharply folded San Pablo formation. They are characteristically exposed about the town of Paso Robles, hence the designation. From Paso Robles the beds extend westward toward the Santa Lucia Mountains, and for many miles north and east of that place, filling the valley of the Estrella and its tributaries, and may reach into the Great Valley. The formation consists of conglomerates, sandy and marly clays, as a general thing, but slightly consolidated. The great extent of this formation in the drainage area of the upper Salinas River, its peculiar character and total absence of marine organisms, or organisms of any kind as far as observed, make it appear probable that it is of fresh-water origin, and for these reasons, though it is possibly contemporanous with the marine formation known as the Merced beds, it should be given a distinct name. The strata are generally almost horizontal, but along the Salinas River in particular they are tilted and faulted. Beds of the same character overlie the San Pablo formation in the vicinity of Arroyo Grande.

Fresh-water beds of Pliocene age are widely distributed through the Coast Ranges.[1] Those in the valleys of the upper San Benito and Salinas have been referred to by Lawson as Pliocene delta deposits,[2] and considered the equivalent of the Merced beds. While the latter view is probably correct, there is no reason to consider them delta deposits; on the contrary, they

[1] Monograph No. XIII, U. S. G. S., p. 238; Bull. Dept. of Geol., Univ. of Cal., Vol. I, p. 152; Bull. Dept. of Geol., Univ. of Cal., Vol. I, p. 363.

[2] Bull. Dept. of Geol., Univ. Cal., Vol. I, p. 153.

have decidedly the character of fresh-water lake beds, and there is no reason to believe that they were ever connected with the Merced beds.

PLEISTOCENE.

Under this designation are included the terrace formations, blown sand, stream gravels, and alluvial bottoms. These were not all formed at once, but represent a complicated history. The terrace formations belong to the oldest division. The most extensive area included under this head embraces a great stretch of sandy mesas and hills between the mouth of the Arroyo-Grande Creek and the Santa Maria River.

The coast, almost everywhere more or less distinctly terraced, forms an elevation of about ten feet above mean tide up to 750 feet. In addition terrace-like effects were noted upon the southern slope of the Santa Lucia range at elevations of 1000, 1400, and 1700 feet, aneroid measurements. In many places along the upper Salinas there are beautiful examples of river terraces cut upon the Paso Robles formation.

IGNEOUS ROCKS.

The igneous rocks of the San Luis Obispo region form one of the most interesting features of that field. Intrusives and surface flows are numerous, especially the former. They are so abundant in the Golden Gate series as in many places to form fully one-third of the surface exposures. The extensive sheets of diabase and peridotite appeared during the Cretaceous, and a great variety, though of much lesser extent, during the Miocene. The age of the andesite and dacite granophyre forming the buttes reaching from San Luis Obispo to Morro Bay cannot be determined with certainty. It certainly antedates the peridotites which appeared at the close of the Knoxville and may be of pre-Cretaceous age.

The igneous rocks, all taken together, show a great range in chemical and mineralogical composition, with examples of rare and interesting types. They have not yet been thoroughly

studied, and no detailed description will be attempted in the present paper.

In the following outline the main types of igneous rocks occurring in this field will be given and arranged in groups according to age:

Granite,	Earlier than the Jurassic.
Basalt, intrusives and surface flows, Peridotite, Diabase,	Earlier than the Cretaceous. Intrusive in Golden Gate series.
Dacite granophyre, Andesite granophyre,	Earlier than the Middle Cretaceous. Possibly pre-Cretaceous. Intrusive in Golden Gate series.
Diabase,	Earlier than the Chico. Intrusive in Knoxville beds.
Peridotite, serpentine and related feldspathic rocks, including diabase, gabbro, and pyroxenite,	Earlier than the Chico. Intrusive in the Knoxville and preceding diabase.
Rhyolite, Augite teschenite, and olivine diabase, Quartz basalt, Basalt,	All probably earlier than San Pablo formation. Intrusive in Monterey series.

The granite covers a large extent of country east of the upper Salinas River. It is remarkably uniform, consisting of quartz, biotite, orthoclase, plagioclase, and titantite. Large orthoclase phenocrysts give a porphyritic aspect in places. Numerous dikes of a finer-grained granite intersect it. Nothing is known concerning the age of the granite, save that it forms the southeastern continuation of the crystalline axis of western Monterey county, on which the Golden Gate series rests with a basal conglomerate. It is certainly much older than the Jurassic.

The dikes of basic pre-Cretaceous intrusives in the Golden Gate series are almost innumerable, and, as they are generally much altered, weather away readily and are difficult to map accurately. Owing to the disturbances which the series has undergone, it is also almost impossible to distinguish in all cases the surface basalts from the dikes with similar appearance. The

greater number of the dikes are fine grained and amygdaloidal on the edges. Dikes of diabase are also numerous. The rock having the most limited distribution is the peridotite. This is not as much decomposed as might be expected, considering its

Morro Rock (dacite granophyre) on the coast at mouth of Morro Bay.

age, and consists of olivine, a rhombic pyroxene, and sometimes augite and a little feldspar. The dikes follow the strike of the rocks, and are more abundant in the jasper horizons. Contemporaneous flows were not recognized with certainty, and it is the writer's opinion that they are more rare upon the San Francisco peninsula than Lawson has supposed. They are not all of the same age. The surface flows did not take place until after the Golden Gate series had been upturned and planed off. This is shown in the hills east of Los Osos Valley.

The dacite and andesite granophyres are strikingly interesting rocks. The occur as roundish or lenticular plugs forming the large buttes, besides many small ones, between San Luis Obispo and Morro Bay. The dacite variety is confined to sev-

eral of the northern ones, the andesite to those nearer San Luis Obispo. The important constituents of the former are quartz, biotite, and an acid plagioclase feldspar; of the latter labradorite, biotite, and enstatite, as porphyritic constituents in a granular base. Morro Rock is the most striking topographic feature on the coast of California.

The diabase intrusive in the Knoxville beds has a character different from any other rocks in the region under investigation. It is grayish in color, fine grained, and amygdaloidal upon the edges. It has come up in great dikes or sheets on either side of the main Knoxville area, throwing the latter into a synclinal trough. It extends northwest from Cuesta Pass for many miles, and is quite uniform save for local gabbroitic variations.

The peridotites and related feldspathic rocks of the Coast Ranges are well known. The great body of this rock in the San Luis Obispo region has been changed to serpentine. It consisted originally of olivine and augite. Local variations rich in feldspar occur along the Santa Lucia range forming diabase and gabbro. The feldspathic facies is quite extensively developed not only upon the borders of the great serpentine area north of San Luis Opispo, but also in many places as apparently independent intrusions. From their similarity in character it is easy to see, however, that all these rocks are genetically related. The serpentine has the usual sheet or lense-like character conformable to the dip and strike of the inclosing rocks, which usually stand very steeply.

The igneous rocks of Tertiary age have a great range in chemical and mineralogical composition. The succession of these rocks was only partly determined. The oldest is the rhyolite of which there are two varieties. One contains free quarts and occurs as a very limited surface flow, being mostly represented by tuffs. The other has the form of long, narrow sheets intruded near the base of the Miocene, and contains no free quartz, but an abundance of plagioclase phenocrysts. The ash which is so widespread at this horizon appears to be connected with rhyolite eruptions, but these particular sheets are

probably of later date, as they are clearly not surface flows. The ash reaches in places a thickness of many hundreds of feet, and in the hills south of San Luis Obispo passes downward into an agglomerate of bowlders of perlitic glass, many of them of large size.

The surface flow of rhyolite on Old Creek is very interesting. It is only a few feet in thickness and imbedded in a great mass of tuffs of the same character. The sheet terminates at one edge in flattened nodular masses from one-half inch to eight inches in diameter. Some of these are entirely free, others more or less connected in the plane of flow. Superficially many of these nodules appear like concretions or large spherulites, but their internal character is entirely different. The flowage lines pass through them regularly without regard to the shape of the surface, and the interior appears to have shrunken away from the center, from which radiating cracks either empty or filled with chalcedony spread toward the outside. These cracks break across the banding with but little disturbance of the latter. They do not appear to be real spherulites and the field relations suggest that their peculiar character may be due to sudden cooling under water.

The augite teschenite and olivine diabase form two generally distinct variations of one magma. The former rock contains varying proportions of analcite and its alteration products, augite and a basic feldspar. The typical examples are rather light colored rocks, but with the appearance of olivine and a decrease of feldspar and analcite the rock becomes very dark and basic looking. Some of the olivine diabase contains so little feldspar that it might with almost as much propriety be termed a peridotite. These rocks are among the most interesting of any yet discovered in the Coast Ranges, and as far as is yet known the augite-teschenite is confined to Santa Barbara and San Luis Obispo counties. It has been described in former papers.[1] Not only is it petrographically interesting, but remarkable for its structural relations to the Miocene in which it is intruded.

[1] Bull. Depart. of Geol., Univ. of Cal., Vol. I, p. 273; *ibid.*, Vol. II, p. 19.

The quartz basalt occurs in the form of dikes intruded at the base of the Miocene east of Edna. The larger one is nearly continuous, following the strike of the rocks for two and one-half miles. The rock is dark and fine grained with a few scattering phenocrysts of labradorite feldspar. The most important phenocrysts are quartz scattered in a fairly uniform manner through the rock. The quartz grains show the effects of corrosion and are surrounded by augite microlites. The analysis shows that the rock has a rather low percentage of lime, but there can be no doubt that it belongs among the basalts.

Other Tertiary basalts occur on a small scale at several different points, but they have no striking features and will not be described here. It is impossible to determine the relative ages of these basic igneous rocks, although it would seem that with the exception of the rhyolite they followed the disturbances which folded the Miocene.

STRUCTURAL GEOLOGY.

Nearly all the structural features have a linear arrangement along northwest and southeast lines. The mountains are structurally synclines elevated by comparatively recent movements, the most important being faulting. This region may be divided in a general way into five crustal blocks, as follows, beginning on the north: the granite and associated rocks north of the Salinas Valley, the depression occupied by the Salinas Valley, the Santa Lucia range, the western foothills of this range and the broad valleys at its southern base, and last, the San Luis range. Each of these blocks has behaved as a unit since Miocene, or in several cases very much earlier times. All the faulting now recognizable dates from later Neocene time. The Santa Lucia range constitutes a remarkable fault block. It has been elevated, not by a single fault on each side, but in most places by several forming step faults. A fault line follows the lowest portion of the Salinas Valley, and other lines of folding and faulting are to be seen along the northern slope of the Buchon range.

One of the most striking structural features is the occurrence in the Monterey shales of the Buchon range of great bodies of bituminized sand forced into its present position during the folding which terminated the deposition of the San Pablo formation. There are two of these sand pockets or bosses north of Sycamore Springs. They occur near the ends of subordinate anticlinal folds. The largest body of sand is fully 500 feet across, elongated somewhat in the direction of the strike of the shales and with narrow dikes radiating from it. The sand has probably been forced in from beneath from the adjoining San Pablo formation, as the nose-shaped terminations of the anticlines in which the sand appears have been forced slightly over that formation.

The structural relations of some of the igneous rocks are quite remarkable. Especially is this true of those which have appeared in the Monterey series. Bodies of the teschenite and olivine diabase magmas have come up underneath this series but have rarely if ever broken completely through it. Having penetrated as far upward as the limestones or bituminous shales they have spread out between the strata in sheet form. Two remarkable cases occur north of San Luis Obispo between it and the railroad water tanks. Here are two hills, one a half mile in diameter, the other nearly a mile, rising quite abruptly from the lower rolling country and capped by a thin layer of Monterey limestone and shale. Each hill has an amphitheater-like center, the strata dipping inward from all sides but one, and from this a depression has been eroded. The peculiar topography and saucer-like structure is due in each case to a sheet of teschenite which outcrops around the steep outer slope metamorphosing the overlying rocks. From a general study of the region it seems likely that the Monterey series had already undergone disturbance and folding when these igneous rocks appeared.

One of the crests of the Santa Lucia range about 20 miles north of San Luis Obispo has on its summit a long narrow remnant of Monterey shales folded in synclinal form. For some

miles the center of this syncline has been broken through by bodies of olivine diabase. They appear as dikes or bunches which as exposed in places have lifted up and inclosed large masses of the shale.

On Old Creek there are very large sheets of the diabase, from the upper surface of which the Monterey shales have been nearly removed, as they occur only in patches here and there. These igneous masses in many respects resemble laccolites, only that instead of having arched the strata in dome form they appear as saucer-shaped sheets issuing from lines of fracture along centers of synclines.

GEOLOGICAL HISTORY.

The geological history of this region is exceedingly complicated, and in the short review following only the merest outline can be given. The earliest event of which we have any record in the Coast Ranges was the invasion of the crust by great masses of molten granite, metamorphosing the existing sediments to marbles and schists. The date of this convulsion is unknown save that it must have long antedated the Jurassic. With the beginning of the deposition of the Golden Gate series the great area of crystalline rocks which had for so long a time formed a land mass in the region of the present Coast Ranges began to subside and continued to do so with oscillatory movements until its close. Although this formation is so widespread it is essentially a near shore or shallow water formation as it consists so largely of sandstone. The conditions at times changed and the sea bottom instead of being subjected to sedimentation from the land was covered with the siliceous skeletons of radiolaria which it is believed form the main portion of the lenticular jasper beds.

With the upheaval of the series, and in some cases possibly earlier, appeared dikes and sheets of basic igneous rocks which everywhere so abundantly characterize it. After erosion had planed off the surface flows of basalt took place.

The period of the intrusion of the more acid plugs forming the line of buttes between San Luis Obispo and Morro Bay is

not exactly known. It may have taken place before the deposition of the Knoxville beds.

With the beginning of the Cretaceous the Coast Range region sank and the thin bedded sandstones and dark shales of Knoxville age were formed. They lie unconformably upon the upturned strata of the Golden Gate series and their basic intrusives.

At the close of the Knoxville a disturbance not heretofore recognized in the Coast Ranges took place and the great masses of diabase were formed which threw the beds of that age along the Santa Lucia into a synclinal form. Before the beginning of the Chico another important event took place. This was the welling up of vast bodies of peridotite, now altered to serpentine, which appear everywhere in the Coast Ranges in rocks older than the Chico. Dikes of serpentine penetrate the diabase just referred to and are therefore younger. It is then clear that the conglomerate at the base of the Chico and the nonconformity of this formation upon the Knoxville is due to a widespread disturbance resulting in an elevation of the region above the sea during a portion of the Middle Cretaceous.

The Eocene is absent from this portion of the Coast Ranges and it is legitimate to infer that the region was above water during the whole period.

Before the inauguration of the Neocene sinking commenced, and we find rocks of this period everywhere underlaid by a conglomerate formed as the sea encroached upon the land. Shortly after the beginning of the deposition of the Monterey series violent volcanic disturbances are recorded as having taken place. Local flows of rhyolite occurred and ash of that composition in the form of glass was thrown out in vast quantities and distributed over the sea for many miles. Following this the bituminous shales and limestones were formed. They consist almost wholly of organic material, the more or less blended and broken skeletons of foraminifera, diatoms, and radiolaria. A very extended period of time must have been required for the deposition of 5000 feet of these sediments which are believed to accumulate

slowly. Peculiar conditions must have existed, the sea being practically free from detrital material though the area of deposition could not have been far removed from the land.

The latest igneous action in this region probably followed the initial folding of the Monterey series preceding the deposition of the San Pablo formation, when the basalt, teschenite, and olivine diabase appeared.

After a period of elevation and prolonged erosion during which the great thickness of Monterey series was totally removed from some areas, and the shales of that period had undergone a chemical change, a subsidance began and the sandy strata of the San Pablo formation were laid down. The present configuration did not exist and this formation probably spread across the Santa Lucia range.

The discovery of the nonconformity of the San Pablo formation upon the bituminous shales (Monterey series) necessitates the addition of a correction to the diagram recently published illustrating the oscillations of the Coast Ranges.[1] Two oscillations should appear where the one is represented as separating the Miocene and Pliocene, with the understanding that the dividing line between these two periods is not at present settled.

After a deposition of at least 3000 feet of sediments, elevation and folding were experienced, terminating the San Pablo period; and the outlines of the present mountains were originated.

Marine formations of late Neocene age have not with certainty been recognized in this region. The Paso Robles formation indicates the existence of fresh-water lakes of large extent. With the close of the Neocene an upward movement was inaugurated and continued, it is believed, until the region was much higher than at present.

Following this early Pleistocene elevation a reversal took place and sinking went on until the coast was submerged to the depth of the highest terraces. With the gradual recovery from this depression the lower terraces were formed and again a point

[1] American Geologist, Vol. XX, p. 225.

was reached somewhat above the present. How much this was is not known for the mouths of all streams have been flooded by the ocean. The last movement has been one of subsidance as shown not only by the flooded stream mouths but by Morro Bay, a sheet of water whose origin can only be accounted for by the theory of a depression.

It is hoped that the foregoing discussion will convey some conception of the interesting and complicated problems encountered in the geology of the Coast Ranges.

HAROLD W. FAIRBANKS.

BERKELEY, CALIFORNIA.
June 8, 1898.

THE MIDDLE COAL MEASURES OF THE WESTERN INTERIOR COAL FIELD.

THE most important coal field west of the Mississippi, so far as present development is concerned, is that which stretches from north central Iowa across portions of Missouri, Nebraska, Kansas, Arkansas, Indian Territory, and into Texas. In recent years there has been a good deal of geological work done within this field and some of the older conceptions of its stratigraphy are being changed. It is proposed to discuss here certain problems relating especially to the northern end of the field; that portion extending from central Iowa to southwestern Kansas.

The first extensive investigations of the geology of the Iowa-Missouri coal field were those of Owen[1] who traversed the main streams crossing the region and correctly outlined its limits. He determined the base of the Coal Measures and discovered many important facts with regard to structure and general geology, but made no attempts to build up a general section nor to divide the beds into minor formations. His successors, especially Swallow, Broadhead, and White, applied themselves to this task. Swallow, in an introductory statement regarding the Coal Measures of Missouri,[2] says that they appear to be separated into three divisions by two very important sandstones. These three divisions he calls "Upper," "Middle," and "Lower Coal Series." With the change "series" to "measures" this terminology was generally followed by writers on this region up to 1893 when Keyes, having previously noted the doubtful utility of the term Middle Coal Measures,[3] suggested that the beds were better considered to form two formations which he named the Missouri and the Des Moines.[4] In the succeeding reports of

[1] Geol. Surv. Wisconsin, Iowa, and Minnesota, 1852.
[2] Geol. Surv. Missouri, I and II, p. 78, 1855.
[3] Bull. Geol. Soc. Amer., Vol. II, pp. 277–292, 1891.
[4] Iowa Geol. Surv., Vol. I, p. 85, 1893.

the Iowa and Missouri surveys the beds formerly referred to the Middle Coal Measures have been considered to form a subordinate division of the Des Moines. In Kansas, Haworth has recognized a series of formations of which he correlates the lowermost, the Cherokee shales, with the Des Moines.[1] Above the Cherokee shales and below the Erie limestone, which is at least in a general way equivalent to the Bethany limestone, are placed the Oswego and Pawnee limestones, which with the interbedded shales, would seem to be the equivalents of the Middle Coal Measures of the older classification. Since the earlier work there has been less attempt to build up general sections of the Coal Measures of this field and the tendency has been rather to emphasize the diversity of the beds and the lack of continuity of the strata.

Non-persistence of individual strata is more or less characteristic of all shore formations. It is exceedingly difficult to conceive shore conditions under which beds could be deposited without this being true. When in addition it is remembered that there is excellent evidence that the particular shore line along which the lower Coal Measures of this field were laid down was unstable and subject to change through a considerable vertical range, it will be seen that the attempt to define subordinate formations in the Coal Measures cannot well be expected to yield satisfactory results. All the minor groups which are recognized may be expected to prove of local importance only.

The beds of the upper portion of the Coal Measures, however, beginning with the base of the Missourian formation, indicate that they were found under radically different conditions. Individual bands of limestone, ten feet and less in thickness, may be traced step by step for one hundred or two hundred miles.[2] Bands of black shale, the "slate" of the miners, a foot or less in thickness, seams of impure coal measured in inches only, and thin ledges of impure black limestone of the type elsewhere

[1] Univ. Geol. Surv. Kansas, Vol. I, p. 150, 1896.

[2] Bethany Limestone at Bethany, Mo., H. FOSTER BAIN; Am. Jour. Sci., (4), Vol. V, pp. 433-439, 1898.

least constant in character, maintain themselves over areas of many miles. All of the beds, whether they be limestone made up of beach-rolled fragments, shale suggesting the infra-littoral zone of deposition, or the pure heavy limestone probably marking open sea deposition, are of such uniformity as to force the conclusion that only under conditions of widespread stability could they have been formed. In Kansas and the southern portion of the field there was an important recurrence of shore conditions later in Missourian time. In the portion of the field immediately under discussion, however, this later period of shore conditions is much less important and the uniformity which marks the opening of the Missourian, seems to have persisted throughout the period.

The change from the condition obtaining in the early Des Moines to those present when the Missourian began was a gradual one. During the former period there was no uniformity anywhere, and the field was broken up into a multitude of minor basins of deposition each the theater of an individual sequence of events, while during the latter the whole of southwestern Iowa, northwestern Missouri, eastern Kansas, and probably an even larger area, acted as a unit. The turbulent conditions of the earlier period became merged into the uniform conditions of the later one. Gradually larger and larger areas came to act together and local sequences came to have a wider and wider applicability. It is the beds of this intermediate period which were recognized as the Middle Coal Measures and in the absence of unconformity it will be seen that there is *a priori* reason to expect a series of beds intermediate in character and position between the typical Des Moines and the recognized base of the Missourian. All who have written on the subject have recognized that the Coal Measures mark a continuous sequence of deposition with only local breaks. Any divisions must be more or less arbitrarily established though they may be none the less useful.

The earliest complete section of the Middle Coal Measures published was that of Swallow.[1] A comparison of the plates

[1] Geol. Surv. Missouri, I and II, pp. 82–86, 1855.

given by him with the general section published by White[1] shows a great similarity in the character of the beds, and parts of his section even show a general similarity of sequence. The section given by White was based largely upon investigations carried on along the Raccoon River in central Iowa, a region recently restudied by the present Iowa survey. The section made out in the course of the present work is much the same as a portion of that earlier published. There are, however, certain changes of importance. The upper part as originally published[2] is essentially as given below, the original section numbers being retained.

		Feet
44.	Arenaceous shale and sandstone,	10
43.	Bituminous shale,	4
42.	Lonsdale coal,	2
41.	Shales, light and blue,	15
40.	Limestone,	5
39.	Shales, light red, blue, arenaceous,	30
38.	Limestone, impure, dark blue,	2
37.	Bituminous shale and coal,	3
36.	Shales, yellow and blue,	5
35.	Sandstone,	10
34.	Shales arenaceous, yellow and blue,	15
33.	Marshall coal,	1½
32.	Shales, blue and yellow,	8
31.	Limestone, impure, fragmentary, bluish buff,	2

These beds vary more or less in thickness, but maintain the same sequence over a considerable area.[3] The Lonsdale coal is still worked at the type locality and lies about thirty feet below the base of the Bethany limestone. The heavy sandstone, No. 35, is well exposed and easily recognized. Below the section as given there is a sequence composed mainly of shales estimated to be about 150 feet thick. Below this in turn is a series almost identical with that just quoted, but in which

[1] Geol. of Iowa, Vol. I, pp. 272, 1870.

[2] WHITE, loc. cit.

[3] Geol. Guthrie county, Iowa, Geol. Surv., VII, pp. 428–446, 1897; Geol Madison county, *ibid.*, pp. 504–509; Geol. Dallas county, *ibid.*, VIII, pp. 78–82, 1898.

the coal seams are named Wheeler, Panora, and Lacona respectively. One of the results of the recent work has been to show that this presumed lower sequence is in fact a repetition of the upper portion, brought about by gentle folding.

In following down the South Raccoon River and many of its tributaries the beds already enumerated are easily recognized.[1] A portion of the section is exposed upon Middle Raccoon southwest of Linden, where it is seen to be essentially the same as originally given by St. John.[2] According to the interpretation of that author the beds found in passing both up and down the river from this point were lower. Below the section already quoted he placed a thickness of 145 feet of sandy and variegated shales, and below these a series including three seams of coal and with a sequence remarkably similar to that found above the shales.[3] This hypothesis would require that the beds should rise between Panora and Linden enough not only to compensate for the fall of the stream but to throw high above the river strata deeply buried at the latter point. All dips in the region are slight and the one required here would be greater than any known to be present. Furthermore, recent studies show that the dip from Panora north is in exactly the opposite direction. It seems accordingly that the beds at Panora are to be correlated with the section already given rather than placed below it.

Traveling down the Middle Raccoon the beds rise to Redfield, at which point a thick, massive sandstone fifty feet thick is exposed below them. Below Redfield the sandstone declines and the same sequence as was seen at Linden may be made out.[4] In the southeastern corner of the county the lower portion of the section previously quoted is present overlying a mass of variegated shales. These shales are seen in Polk county, east of Dallas, and only the upper part presents any evidence of regularity. They extend down to the base of the Coal Measures and contain the bulk of the workable coal. The portion

[1] Geol. Guthrie county, pp. 436–437.

[2] See Geology of Guthrie county, p. 430.

[3] See for comparison, Geol. Guthrie county, p. 429.

[4] Geol. Dallas county, pp. 64–67.

which is more or less regular in sequence does not correspond to the lower portion of the Middle Measures as originally described,[1] but shows very different succession.

The Des Moines beds, then, in the central portion of the state consist of a thick mass of shales and sandstones, showing no definite order of arrangement which may be recognized over any considerable area, covered by more regular sequence of which the upper portion may be recognized over a considerable area; but as one travels south two changes take place. (1) The upper member of the section, No. 44, thickness from barely thirty feet on the South Raccoon to over seventy feet on Middle River near Winterset. (2) The various members of the section thin out and are replaced until in the southeastern portion of Madison county none of them can be made out. The section immediately below the Bethany limestone in the latter region is given below. It will be noticed that while none of the beds of the previous section can be recognized, the general character of the strata is the same.

	Feet	Inches
22. Shales, drab, argillaceous, with abundant *Derbya crassa*, *Chonetes*, probably *Chonetes parvus* Shum, at the top,	12	
21. Shales, red, argillaceous,	3	
20. Limestone, fragmental, earthly, with bits of fossils,		2
19. Shale, blue to green, argillaceous, grading into red below,	3	
18. Shales, blue to green, sandy, with nodular segregations of limestone,	12	
17. Shales, blue, calcareous,	12	
16. Limestone, compact,		2
15. Limestone, fragmental, loose, with young *Chonetes mesoloba*,		10
14. Limestone, fragmental, but firmly cemented, reddish color, with *Spirifer cameratus* and *Productus costatus*,	1	
13. Shales, green, argillaceous,	29	
12. Limestone, blue to black, in two ledges, with *Spirifer cameratus*, *Rhynchonella* and *Productus*,	1	
11. Shale, carbonaceous,	2	
10. Shale, clayey, drab,	1	

[1] Geol. Polk county, Iowa Geol. Surv., Vol. VII, pp. 302–310, and Geol. Iowa (White), Vol. I, pp. 272–283.

	Feet	Inches
9. Shale, yellow, sandy, with marked horizontal bedding planes,	4	
8. Shales, black to drab, carbonaceous,		6
7. Limestone, nodular, sandy, with *Productus cora*, *Chonetes mesoloba* and *Athyris subtilita*,	1	4
6. Shale, gray, sandy,	3	
5. Limestone, similar to number 7,		10
4. Shale, clayey, drab to blue,		10
3. Shale, carbonaceous,	1	
2. Limestone, thin bedded, leaf-like in texture, with *Productus muricatus*, *Chonetes mesoloba*, *Derbya crassa* and *Productus costatus*,		3
1. Clay, green,	3	

South from here in Clark and Lucas counties the work has not yet been carried on in sufficient detail to allow a general section to be made out. It is, however, known that there are in the region strata of the same general type as those found in Madison, Dallas and Guthrie counties, though probably detailed correlation will be impossible.

Along the southern border of the state the Des Moines beds outcrop from the Mississippi River west to Decatur county, where they become buried beneath the Bethany. As far west as the Chariton River the beds may be referred unhesitatingly to the lower division, corresponding, as noted above, with the Cherokee shales. Their character is shown in exposures and mine sections along the Chicago, Milwaukee and St. Paul Railway from Ottumwa southwest.[1] Above these is a formation, including several limestone beds and one widely worked seam of coal, which has been called the Appanoose formation.[2] In general character these strata correspond to those seen farther north at the same horizon. A generalized section is given below:

	Feet	Inches
17. Limestone, gray, subcrystalline, seen in the railway cut near Anchor No. 1 mine at Centerville, and known among the miners as the "floating rock,"	2–4	
16. Shale, argillaceous, color variable,	12–30	

[1] Iowa Geol. Surv., Vol. V, Pl. XIV. [2] Iowa Geol. Surv., Vol. V, pp. 378-394.

	Feet	Inches
15. Limestone, heavy ledges, exposed along Manson branch and Cooper Creek at Centerville, as well as at numerous other points in the county, the "fifty-foot limestone,"	4–10	
14. Shale, argillaceous, blue and red in color,	14	
13. Shale, arenaceous, frequently forming a well defined sandstone, as in boring No. 3 (No. 13), and the Rock Valley shaft,	8	
12. Shale, argillaceous, blue to gray,	10	
11. Limestone, somewhat variable in thickness; exposed along the C., M. & St. P. railway, between Mystic and Brazil, known as the "seventeen-foot limestone" or "little rock,"	1–3	
10. Shale, sometimes gray, frequently bituminous and pyritiferous,	7	
9. Limestone, sometimes gray, and coarsely sub-crystalline as at the Lodwick mine, Mystic; sometimes fine-grained, bituminous, and grading into the shales above and below, as at the Thistle mine, Cincinnati; known as the "cap rock,"	2–4	
8. Shale, usually bituminous, and known as "slate;" occasionally in part soft and clay-like, then known as clod; at times heavy and homogeneous non-fissile, in which form it is known as "black bat,"	1–3	
7. Coal, upper bench, usually,	1	8–10
6. Clay parting "mud band,"		2– 3
5. Coal, lower bench, usually,		8–10
4. Clay parting the "dutchman,"		½
3. Coal, frequently not so pure,		2– 3
2. Fire clay,	1–6	
1. Limestone, "bottom rock," well exposed along Walnut Creek at Mystic,	3	6

This section was first made out in 1893 and published in the following year.[1] It was not, however, until 1896 that the name Appanoose was applied to the beds. At this time[2] they were defined as a subdivision of the Des Moines formation and sections were given illustrating their relations to the underlying and overlying strata. Above the Appanoose formation there is

[1] Amer. Geol., XIII, 407–411; Proc. Iowa Acad. Sci., Vol. I, Pt. IV, 33–36; Iowa Geol. Surv., II, 407.

[2] Iowa Geol. Surv., V, 378–394.

at one point an unconformable conglomerate.[1] Little is known of this formation, but it seems to be essentially local. The beds between the upper member of the Appanoose, the "floating rock" of the miners and the lowermost member of the Bethany as shown in Decatur county are but infrequently exposed and little is known concerning them. If one may judge from the topography and the infrequent exposures, the intervening beds are shales, predominantly sandy.

The three Iowa sections from the St. Louis limestone to the Bethany may be summarized as below:

Northern Section: Jasper, Polk, Dallas, and Guthrie counties	Feet	Middle Section: Monroe, Lucas, and Clark counties	Feet	Southern Section: Van Buren, Davis, Appanoose, Wayne, and Decatur counties	Feet
3. Sandy shales not to be separated from the underlying formation,	30	3. Beds covered; probably sandy shales,	50–70	3. Sandy shales, only partially exposed, (Chariton Conglomerate, local.)	75
2. Shales, limestone, three coal beds, upper portion of old Middle Coal Measures, -	100	2. Equivalents, section not yet made out,	100	2. Appanoose beds, -	100
1. Shales, heavy sandstone and non-persistent but thicker coal beds, -	400–500	1. Equivalent and similar beds, -	200–400	1. Equivalent and similar beds, -	400–600

The lowermost division is clearly the equivalent of the Cherokee shales of Kansas. The variation in its thickness is due to the erosion unconformity between it and the underlying St. Louis limestone. The middle division exhibits the same general characteristics of thin persistent limestone and coal

[1] Loc. cit., pp. 394–398.

beds throughout the state but varies in detail so much that it is impossible to correlate the individual beds of the north, middle and south sections. The uppermost beds represent a recurrence of the type of sedimentation shown by the lower member and present a notable thickening to the south. Indeed this member is practically absent at the northern end of the area so that the Iowan field includes apparently only the northern half of an immense lense of sandy material, intercalated between the limestones of the Bethany and the Appanoose formations.

As has been pointed out by Keyes[1] there is a close correspondence between the sections made out in Iowa, Missouri, and Kansas. These may be summarized as below.

	Iowa	Missouri	Kansas
3.	No name	Pleasanton	Pleasanton
2.	Appanoose	Henrietta	Pawnee Oswego
1.	Cherokee	Cherokee	Cherokee

The Middle Coal Measures as originally defined included the two upper divisions noted here. Swallow[2] recognized along the Missouri and at the top of his section some thirty feet of sandy shales. White and St. John found about the same thickness along the Raccoon River. Between these two points it is now known that the sandy member attains a considerable thickness and becomes sufficiently distinct to perhaps warrant giving it a separate designation. For this division Haworth's term Pleasanton[3] seems to have precedence if the beds are to be considered as distinct from the next lower formation.

The middle member of the above table includes the major

[1] Proc. Iowa Acad. Sci., Vol. IV, pp. 22–25, 1897.

[2] Op. cit., pp. 82–83.

[3] Kan. Univ. Quart., Vol. II, p. 274, 1895.

portion of the old Middle Coal Measures. As now defined, this median member forms a single well-defined formation, with certain uniform characteristics, and may be well recognized as a distinct unit. Toward the north limestones are thinner and more numerous, while to the south they come together and thicken, until in Kansas they form two well marked beds to which Haworth has given the names Oswego and Pawnee. The Henrietta limestone of Marbut[1] in southwestern Missouri seems to include these two limestones with an intervening shale bed. The whole forms a well defined escarpment which Marbut has traced across the southwestern portion of that state. No detailed section of the Henrietta formation has yet been published, so that the correlation of its individual beds cannot yet be made. In north central Missouri the formation seems to resemble more closely the beds found in southern Iowa, since the Mystic coal is widely recognized in Putnam, Schuyler, and Adair counties.[2] The whole series of sections would seem to indicate a gradual change of character, from the near shore beds of the Raccoon River section to the off shore beds of Kansas. This change is very gradual as the series of sections is taken parallel to the strike.

For this median member of the Des Moines series no good term has yet been proposed. The designations used in Kansas refer to individual parts of the formation. The name Henrietta and Appanose have been applied to distinctive phases of the formation. No general term has yet been used for the Raccoon River beds. If it is thought best to apply to the whole formation one of the names already in use, it would seem that Appanoose would have precedence as being first clearly defined and located. There are, however, objections to this since the Appanoose formation as now defined is coextensive with an important coal bed and hence has a definite economic significance. Henrietta has been used in the general sense here suggested,[3]

[1] Missouri Geol. Surv., Vol. X, p. 44, 1896.

[2] Proc. Iowa Acad. Sci., Vol. I, Pt. IV, p. 36, 1894.

[3] Keyes, Proc. Iowa Acad. Sci., IV, 23; and Eng. Mining Jour., Feb. 26, 1898, p. 254.

but if this usage is to be adopted it would seem desirable that the formation be properly defined and some general section of it, as typically exposed, be given. Since, however, Henrietta was first applied to a distinctive phase of the formation, that displayed in southwestern Missouri, it will probably be found better in the end to adopt a general term for the whole region, retaining the terms now in use, Pawnee, Oswego, Henrietta, Appanoose, and Raccoon River beds, for local use. This is the more advisable, since, while the beds show certain general characters common to all and are probably of essentially contemporaneous origin, they really contain the record of deposition in four and perhaps more essentially distinct minor geological provinces.

H. Foster Bain.
A. G. Leonard.

KETTLES IN GLACIAL LAKE DELTAS.[1]

THE object of this brief paper is to describe a remarkable basin in a glacial-lake delta in western New York, and to discuss similar phenomena in general only so far as to throw light upon this particular case.

Between Canandaigua and Seneca valleys lie three north and south valleys which hold no lakes. The most westerly of these is the Middlesex or West River Valley, which drains south into the head of Canandaigua Lake. The next is the valley of Flint Creek, which flows north. Eastward is another deep valley which drains south into Keuka Lake, at Branchport. Upon the west side of the middle one of these three lakeless valleys, the Flint Creek Valley, lies the little village of Potter. Close behind the village is a conspicuous plateau of stony gravel rising 250 feet above the valley plain. In the middle of this ancient plain occurs the singular basin herein described.

This delta is one of the many phenomena which record the intricate and interesting history of the glacial waters in the "Finger Lake" region. The events leading up to its formation seem to be as follows: During the recession of the front of the ice-sheet there came a time when the southern or upper end of each north-sloping valley was free of ice, and the impounded waters were forced into southward flow.[2]

In the Keuka Valley the glacial waters were at first compelled to overflow directly south into the Cohocton River at Bath, but they soon found a somewhat lower outlet across the eastern rim of the basin through the site of Wayne village and the chain of small lakes. These waters have been named the

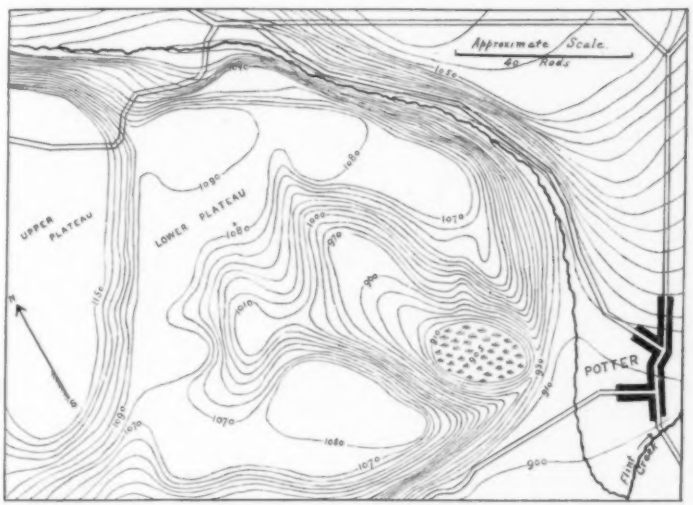
[1] Presented before the American Association for the Advancement of Science, August 25, 1898.

[2] Papers descriptive of the glacial lakes of western-central New York may be found in the Bulletin of the Geological Society of America, Vol. VI, pp. 353–374; Vol. VII, pp. 449–452; Vol. VIII, pp. 269–284.

Hammondsport Lake. Probably somewhat later the southern end of the Canandaigua Valley was occupied by glacial waters, the Naples Lake, which have left a well defined overflow channel near Atlanta. At this level the Naples Lake flooded as much of the Honeoye Valley upon the west, and the West River or Middlesex Valley upon the east, as the recession of the ice-sheet had left open. With further removal of the ice-front a lower outlet for the Naples Lake was uncovered on the eastern border of the Middlesex Valley, about two miles northeast of Middlesex village, and a channel was cut by the escaping waters leading east toward Potter. It was the stream which cut this channel, and drained the waters of the Canandaigua-Middlesex valleys into the Hammondsport Lake, that built the Potter Delta. The ravine is about one mile long. Its depth will average about 100 feet, mostly in shale, with a width at the bottom of about 100 feet, and a uniform gentle grade, with a total fall of about 30 feet. At present it carries no stream. The lower end of this channel is not far above the level of the valley plain of Flint Creek, which indicates that the channel was effective even after the glacial waters in the Flint Creek Valley had found an outlet not far higher than the present plain. Indeed, the gravel and sand plain of the broad valley bottom is probably the filling during the last phase of the glacial waters. The delta represents the earlier deposits at the mouth of the down-cutting stream in the higher or Hammondsport Lake. There are two prominent levels on the delta. Aneroid measurements, using the Lehigh Valley Railroad at Middlesex and Rushville as datum, make the altitude of the valley plain at Potter about 900 feet. The lower and broader delta plateau is about 1080 feet, and the higher, summit plateau about 1150 feet. This higher level corresponds with the summit levels of the several old deltas in the Keuka Valley proper. The lower level represents some stage of the Flint Creek Valley waters not positively correlated at the time of this writing. As the waters fell in the Flint Creek Valley, the ancient stream, continually cutting down to the local base level, bisected and eroded the earlier delta deposits.

While not so extensive as some deposits of similar origin, this delta is a comparatively large one for the ephemeral glacial lakes of the region. By estimate it is about one-third of a mile across.

The form and topography of the delta and the included basin are fairly shown in the accompanying sketch. The dis-



Kettle in Delta at Potter, N. Y.

tances are by eye-estimate and the elevations by aneroid. While the absolute elevations are not exact, the relative heights are approximately accurate. The sketch does not show the rock cut nor the continuation of the two terrace levels along the ravine upon the north side, these being perhaps one-eighth of a mile north of the area shown in the map. The higher level is there a filling of an angle or recess in the hills, about 40 rods wide and with a bar or ridge on the front. The lower level is represented by a rock terrace about 10 rods wide. Behind the higher plateau, on both sides of the ravine, the ground is lower, with ridges and hollows transverse to the stream direction.

The materials composing the delta are quite variable and poorly assorted, containing an unusual amount of large stones and even boulders. This is epecially the case on the northeast side of the 1080 feet plateau, where several heavy stone fences have utilized only a portion of the field stone. These, however, might be wholly attributed to the powerful stream, but many larger and angular boulders on the slopes of the basin are not so explained.

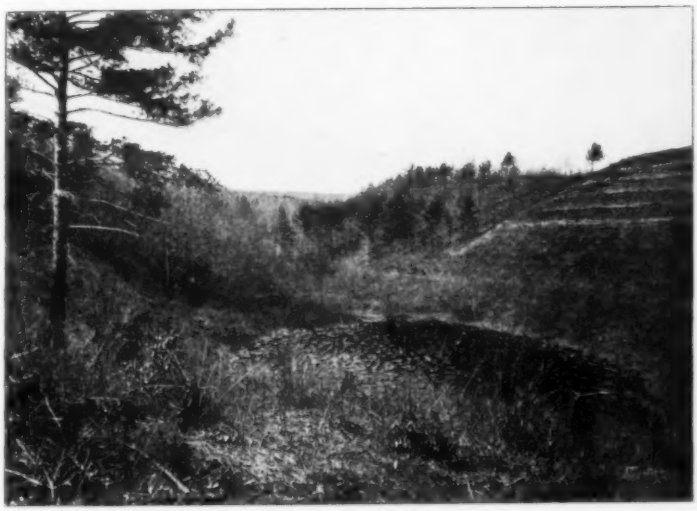
Of the origin of the kettle two hypotheses have been considered; one, that it was a result of capricious currents and deficient filling, the other that the basin is a portion of the space occupied by a block of ice during the deposition of the delta. The first explanation was suggested by the form of the spitlike, sloping ridges on either side of the swamp, the location of the deepest part of the basin at the extreme edge of the delta, and by the existence, in other deltas, of smaller kettles apparently produced by the aqueous forces alone. This explanation is now thought inadequate for the Potter basin.

During the study of this feature correspondence was held with Professor J. B. Woodworth, from whom valuable suggestions have been received. The sketch and photographs were sent to him, and he thought the Potter phenomena similar to other basins which he had studied in New England, and the genesis of which is confidently referred to ice-blocks. The writer accepts this theory for the origin of the Potter basin.

The deepest part of the basin is an oval swamp which holds water until removed, apparently, by evaporation. This indicates an impervious bottom. The depth of the vegetal accumulation is undetermined, but it seems probable that the original bottom of the kettle must have been in till or on rock, and below the water-laid drift. It seems improbable that such a deep hole, with walls so steep, could have been produced as a constructional feature in open water. If such were the case, the spitlike points inclosing the kettle should consist of the finest material brought down by the dying currents. The material, on the contrary, is not sand or even fine gravel, but stony gravel, and the

material of the low ridge at the notch opening into the basin is more like till than it is like gravel. Water movement probably had some part in the formation of the ridges, the currents sweeping about the half buried ice-block.

If the basin were due to deficient filling obviously the inner slopes should consist of finer material dropped by the weakened



Kettle in Delta at Potter, N. Y. View of deepest part looking north.

currents. Such is not the case. The materials are stony, and even large boulders occur. The writer observed no boulders which might not possibly have been rolled by powerful currents, although the much more reasonable explanation would attribute them to ice transportation. The owner of the larger part of the basin said that blocks of stone exist in the basin "as large as a team could haul."

The existence of elevated portions or isolated areas somewhat above the general plateau level might be regarded as due to erosion of the surrounding area, but seem more reasonably

due to contributory deposition by ice, especially as they are quite stony.

The ice-block was probably not entirely buried but projected above the surface of the delta, otherwise the deep swamp kettle would have been partially filled with the water-laid delta material falling in upon the melting ice. The notch at the edge of the kettle is apparently a constructional form, and there is no evidence of any current of water having flowed through it. It is still a narrow ridge, although somewhat flattened or lowered by use for a roadway leading into the basin. The water from the dissolving ice-block probably filtered out through the surrounding gravel.

A natural objection to the ice-block theory is the existence of such an isolated mass of ice for a great length of time. The relations of the stream and delta with the water bodies require the ice-front to be removed some uncertain distance to the northward. This objection, however, has not been given great weight by the students of similar phenomena.

This basin is by far the largest one that the writer has seen in the lacustrine deposits of western-central New York. However, it is not the only one suggesting ice-block genesis. Other deep steep-sided kettles have been seen in the deltas, especially on the slopes of Seneca and Keuka valleys, which may most reasonably be attributed to such origin. The writer has particularly in mind one a short distance above the Hector station, on the east side of Seneca Lake. This seems to lie above the plane of glacial waters and was apparently formed in the exposed delta.

In many deltas, small basins, or hollows, or bowls, occur which have been attributed to aqueous forces alone. These are usually located behind embankments or bars lying transverse to the stream, and vary in form from hollows open at one end to well enclosed kettles. So far as noted, although close study has not been made, the walls are of clear sand or gravel, the depths not great as compared with the breadth, and the forms are simple curves. Their origin seems explained by conflict of waves and

shore currents with the detritus-bearing stream currents. On the lakeward side they are usually bounded by a spit or bar formed transverse to the stream current. Some of the larger and more irregular depressions are bounded landward by the original surface of the valley border, but such are more likely to be open on the side away from the delta-forming stream.

Kettle in Delta at Potter, N. Y. General view, looking northwest from opposite side of Flint Creek Valley.

Those which are confidently referred to aqueous forces occur below the water plane, or are surely subaqueous.

Professor Chamberlin in discussing "kettles," in 1877, suggested four possible methods of origin: (1) Irregularities of deposition or heaping of the drift; (2) the pushing of one drift ridge unconformably against a preceding one; (3) the incorporation of ice-blocks; and (4) under-drainage. To this enumeration the writer would add a fifth method, (5) circum-deposition, by capricious stream currents in the face of wave action, or deficient filling on delta terraces.

The basins which occur in broad stream deposits, and which have suggested the name "pitted plains" have been confessedly difficult of explanation. The notable ones near New Haven have been thought to be due to deficient filling, or to whirling currents in the river. Professor Woodward informs the writer that he is convinced, from his personal examination, that these are of ice-block genesis. Such basins have not been often observed in New York. The best example that has fallen under the writer's observation lies near the village of Tully, upon the south, in the gravel plain left by the glacial waters. It borders the highway leading from the station and village to the Assembly grounds, and is of irregular shape and large extent. The most reasonable explanation is that it was the site of an isolated mass of ice, but whether buried in the gravel or projecting above is not determined, no study of the basin having been made. The occurrence further south, in the same detrital plain, of numerous lakelets, suggests that there are probably many similar basins in the locality.

SUMMARY.

The basins in deltas seem to be divisible into two classes:

(*a*) Those by ice-block origin, and

(*b*) Those by circumdeposition.

These may be discriminated by the following theoretical characters:

(*a*) Shape usually irregular; relatively deep; walls steep; material of the walls coarse or even till-like, with possible boulders; size, often large; position, often above the water-plane. (These characters would be greatly modified in cases where the ice-block was wholly buried in the drift.)

(*b*) Position always beneath water-plane, and usually behind a bar or embankment; depth relatively small; shape, with smooth curving outlines; material of the walls, well assorted and finer than the adjacent delta mass.

HERMAN L. FAIRCHILD.

A SYSTEMATIC SOURCE OF EVOLUTION OF PROVINCIAL FAUNAS.

THE deformations of the outer portion of the solid part of the earth familiarly known as the "crust" are the result of an intricate combination of adventitious and systematic movements. The latter spring from the predominant action of the great stresses that affect the body of the earth; the former, from intercurrent variations in the expression of these dominant agencies due primarily to the rigidity of the earth, and secondarily to inequalities in its density, to changes in its internal temperature, and perhaps to other conditions. Were the earth a homogeneous liquid, the adventitious features would disappear and all its changes of form would be systematic, or if not absolutely all, at least all which seriously affect its deformation. While the adventitious movements that make for heterogeneity of configuration must be recognized, it is the function of the geologist to discriminate and emphasize the systematic factors and to relegate the adventitious elements to their proper subordination.

It is assumed that the fundamental movements which affect the earth's form are centripetal and that the dominant fact in the bodily history of the earth is the shrinkage of its outer parts, as has been so signally urged by Suess. Its upward movements may be regarded as adventitious, since they are incidents due to the restraint which rigidity puts upon a perfect adjustment to the demands of its contractile forces, or to variations from symmetry of substance or of temperature which only become effective through its rigidity. In a slightly different and broader sense, the continents may be said to be adventitious while the ocean basins may be said to be normal. We must hasten, however, to qualify this idea, for the ocean basins have obviously sunk beyond the normal level which the surface of the earth would assume, did not rigidity deform it. The uniform spher-

oidal surface to which an ideal earth would be adjusted lies about 9000 feet below the ocean surface.[1] The portions of the ocean basin below this normal level represent an excess of shrinkage. The continental masses which stand above this average level represent a deficiency in shrinkage. This average level is the natural datum plane from which the continents may be conceived to rise. The ideal upper surface of a continent may be said to be the sea level, a plane which the upper surface of the continent constantly approaches but never entirely reaches. That portion of it which is exposed above the sea level undergoes constant truncation by air and water. The portion beneath the sea level is being constantly built up by the deposition of land wash about its borders, forming a sea shelf whose summit plane is the sea level.[2] As a result of these activities, continued throughout the ages, the continents have come to be approximate platforms whose theoretical upper horizon is the sea level. To this they are accommodated more or less approximately, but never perfectly. They reach their most complete adjustment after long intervals of relative quiescence, when base-leveling attains its highest degree of perfection. They depart most widely from the theoretical surface at the climax of great periods of crustal readjustment to accumulated internal stresses. Such periods of greatest departure inaugurate periods of maximum activity, both on the part of the leveling forces, whose function it is to reduce the land surface again to the sea level, and on the part of the depositional agencies whose function it is to build up a sea-shelf around the borders of the continent. In other words, agencies for the replanation of the platform are put into maximum activity by the very agency which deformed it. If we conceive the continental platform to be the basal portion of a broad truncated pyramid whose bottom rests upon the ideal average level, 9000 feet below the sea surface, and whose truncated summit is ideally at the sea level, it

[1] GILBERT, Article "Earth," Johnson's Cyclopædia.

[2] See "The Ulterior Basis of Time Divisions and the Classification of Geologic History," JOUR. GEOL., Vol. VI, No. 5, 1898, pp. 449–462.

may be said that the widest departure of the average land surface from this ideal summit level has probably at no time exceeded 25 or 30 per cent. of the whole height of the platform, while at times of greatest approximation to the theoretical summit level through base leveling, its departure has probably not reached 10 per cent. of the whole height of the platform. The conception of a continent, therefore, as a platform maintained against deforming agencies by constant truncation of the protruding portions and by constant upbuilding about its borders is not seriously vitiated by the inequalities which crustal readjustments force upon it from time to time.

The ocean basins, considered as inverted plateaus or antiplateaus, have no analagous agency for the reduction of their bottoms to an ideal plain, and their inequalities are greater (in their broad features, but not in detailed accentuation), and yet here is a reasonable approximation to a bottom plain, for more than half of the oceanic bottom lies between 12,000 and 18,000 feet below sea level. But the variation of 6000 feet included between these limits would be regarded as very large if it were a land surface.

More or less warping of the surface of the solid part of the earth is doubtless in progress at all times, but there is much concurrent geologic evidence to the effect that the really important changes are periodic rather than uniformly progressive. The most important items in this evidence are the great base levels and the great epochs of mountain making, the former pointing to long periods of relative quiescence, the latter to exceptional periods of disturbance. In the larger conceptions of the earth movements, the minor warpings may be ignored, but in the interpretation of the details of the earth's history they play a not unimportant part. The degree of importance of this part is dependent upon the critical relationships which the warping may bear to sea-level relations. The present study is concerned with such relationships in their bearing upon the progress of marine life.

The discussion proceeds upon the following general concep-

tions: (1) The continents are platforms whose summits are accommodated approximately to the sea level by truncation and by concurrent circumjacent filling. (2) The normal and the dominant feature of each readjustment of the outer part of the crust to internal contractional stresses is the sinking of the ocean basins and the enlargement of their capacity. (3) The incidental consequence of the sinking of the oceanic basins is the withdrawal into them of an increased amount of the epicontinental waters and the establishment of a new shore line upon the borders of the continent lying at a lower level than the preceding one. (4) The main readjustments are periodic and are separated by intervening stages of relative quiescence. (5) The continental platforms are subject to warping, partly due to the lateral thrust of segments of the earth as they sink (especially those segments that lie beneath the ocean), partly to internal changes of temperature and the intrusion of liquid matter, and partly to the settling of the continent when, by any of the preceding agencies it has been forced upward beyond the plane of isostatic equilibrium, the settling being accomplished through the slow quasi-fluid creep of the rock under gravitative stress.

As a mode of approach to the critical attitudes of sea and land which favor the evolution of provincial faunas, two more general and systematic attitudes which favor respectively general expansional evolution and general contractional evolution may be considered.[1]

1. *Conditions favorable to general expansional evolution of marine life.*— It is to be understood that only that element of marine life is here considered which has for its habitat the relatively shallow sea water adjacent to the land. Geologically speaking we know very little respecting the true abysmal life of the past, and only such little about the surface pelagic life as became incidentally involved in the terrigenous deposits. In considering the shallow-water life adjacent to the land we are, therefore, considering practically that phase of marine life which alone enters effectively into the geologic record. The conditions

[1] These were discussed on pp. 454–459 of preceding number of this JOURNAL.

favorable to an expansional evolution of this shallow-water marine life are those which ensued upon a protracted period of base leveling.[1] This, by its very terms, implies a protracted period of freedom from great movements on the part of the land or the sea. At the climax of such a period there is normally an extensive transgression of the sea upon the continental platform which assumes two phases: (1) the development of broad sea-shelves by the cutting back landward of the sea cliff and the building out seaward of the submarine sea terrace by means of the land detritus; (2) the creeping of the sea waters far inland upon the lower portions of the continent.

At first thought it may be questioned whether the land will not be *extended* by the addition of detritus to its border, and, still further, whether the transgression of the sea is genetically connected with base leveling and is its normal attendant. That the land is now being extended in certain places by detrital accretions to its borders, as in the case of deltas, is beyond question, but it is equally beyond question that the sea is advancing in other places, and it will probably be apparent, after a careful inspection of the continental coasts, that on the average the sea is advancing rather than retiring. But the present is far removed from a base-level period. The streams carry to the sea much more detritus than they would were the surface closely approaching a base level. The sea also, it is to be admitted, is better able to carry detritus back to deep water under present conditions than it would be if its sea-shelf were greatly extended. Conclusions drawn from present conditions are, therefore, embarrassed to this extent on both sides. The issue is really a contest between the ability of the streams to deliver detritus at the coast line and the ability of the sea to carry it back to deep water. The delivery of the streams is a declining factor which approaches zero as the base level is approached. The carrying ability of the sea is much more

[1] A suitable sinking of the land independent of base leveling may produce similar though not quite identical results, but in so far as this is adventitious it does not fall into the category under discussion here.

nearly constant. It is reduced, indeed, by the growing width of the sea-shelf. But the growth of the sea-shelf on its abysmal border must necessarily be slow because of the great depth to be filled, and hence, unless the shelf grows inland, its extension is relatively slight and the ability of the sea to dispose of the detritus borne into it remains nearly constant. With the inevitable decline in the delivery of land wash, as base level is approached, the disposing power of the sea must gain the ascendancy. It would seem to be almost obvious that if there were no movements of the crust for an indefinite period the ultimate result must be the complete truncation of the land to a level below the effective reach of the waves.

But the case does not rest simply with the results of the contest between the diminishing stream action and the nearly constant wave action. There are two supplementary factors which aid the latter. (1) The deposit of the detritus of the land in the sea raises its level. If the average elevation of the present land be taken at Lapparent's figures, 2120 feet, its truncation and removal to the ocean would lift the sea level 700 feet (making no allowance for the spread of the sea). This would certainly be effective in advancing the sea upon the land. (2) The continents after the relative upthrusts attendant upon crustal readjustment probably stand on the average above the plane of isostatic equilibrium, as indicated in the existing status by pendulum observations. From this they should settle back toward equilibrium by virtue of the quasi-fluency of the rocks. The effects of this might, perhaps, decline as erosion proceeded, but the shifting of the load to the borders of the continent would probably aid in depressing them and facilitating the advance of the sea.

The inland extensions of the sea attendant upon such an advance may be conveniently designated epicontinental seas. The great sea which lies between Europe and Africa is properly termed a mediterranean sea, since it really lies between the continents in a deep basin descending to depths of 6000 feet and more. But the seas here referred to as epicontinental are not

of this kind, but are such as are formed by the creeping out upon the low parts of the land of a film of the sea, as it were. The North and the Baltic seas, the Gulf of St. Lawrence and Hudson's Bay are adventitious examples.

It is obvious that at a stage when the sea-shelves and the epicontinental seas were thus extending themselves the conditions for the expansional evolution of shallow-water marine life were signally favorable. In so far as land detritus is inimical to such life, an additional favoring factor is found in the reduction of the surface relief and the consequent diminution of the land wash. The seas at such stages were being not only extended but progressively clarified. A further incident of such stages is the free intercommunication of the life. All of the great continents are at present connected by submerged portions of their platforms and appear to have been so united from the Cambrian times onward. Europe is connected with Greenland by a shallow tract, embracing Iceland, and Greenland, in turn, with the Arctic islands, and thence with the northeastern part of the American continent, constituting a northwest passage for European shallow-water life. On the other hand, Asia is connected by a tract underlying Behring Sea and Straits, and by a broad belt along the border of the Arctic Ocean of unknown width, constituting a northeastern passage for Eurasian life. At times of base leveling there are broad sea-shelves girdling all of the continents, as well as internal epicontinental seas affording other connections; so that altogether the facilities for the migration and the intercommingling of the faunas are exceptionally propitious.

At the same time, as I have endeavored to show in another article in this number,[1] the atmospheric and climatic conditions are uniform and favorable to the widest distribution of life.

In such a period, therefore, is to be found the climax of conditions favorable to expansional evolution and to the development of a world-wide fauna of a composite and comprehensive

[1] The Effects of Great Limestone-forming Epochs upon the Constitution of the Atmosphere, pp. 609.

type. Such faunas appear to characterize the Middle Silurian, the Middle Ordovician, the Carboniferous, and the Cretaceous periods, and in a less pronounced degree the Devonian, the Jurassic, and the early Tertiary.

(2) *Conditions imposing general restrictional evolution of marine life.*—If at the close of a period of great base leveling attended by expansional evolution of marine life, as just outlined, an epoch of profound readjustment to the earth's accumulated contractional stresses ensues, the great feature of which consists of the sinking of the ocean basins or some large part of them, the effect is to withdraw the waters from the surface of the continental platforms into the basins thus increased in capacity and to establish a new shore line somewhere near the edge of the continental platforms. If the enlargement of the capacities of the ocean basins is pronounced, a new shore line may be established, not upon the upper face of the continental platforms, but upon their abysmal slopes. In this case the shallow-water belt will be narrow and will consist of a rapidly shelving shore tract. It is obvious that the great expansional fauna which has occupied the broad sea-shelves and the extended epicontinental seas of the preceding period will be compelled to follow the retiring sea and crowd itself into this restricted zone on the abysmal slope of the continents. It is further obvious that, in addition to the restricted area into which the fauna is thus forced, the new conditions will be in many respects uncongenial, for the streams will be rejuvenated and the amount of land wash will be greatly increased. Those species whose existence is dependent upon clear seas will be in imminent danger of extinction. Certain species to which these conditions are congenial may on the other hand be favored, but the grand result must necessarily be the destruction of the larger part of the previous expansional fauna and the forced adaptation of the remainder to new, and on the whole sterile and hostile conditions. A stage of general repressional evolution is thereby inaugurated and, in a comparatively short period, it is safe to assume, all or nearly all preceding species will have passed out of existence and new species,

in a much more limited number but better adapted to the new conditions, will have been introduced. Such restrictive conditions appear to have been prevalent in a pronounced degree at the close of the Palæozoic era and less notably at the close of the Ordovician period and at other times. But in neither of these cases were the repressional conditions complete, and it is improbable that the ideal conditions of repression here sketched were ever fully realized.

(3) *Conditions favorable to the evolution of provincial faunas.*— It is obvious that if the sea shore be drawn far down the abysmal slope of the ideal sea-shelf, moderate warpings of the continental platform will have little or no effect upon the conditions of faunal development, for whether the shore stands high or low upon this abysmal face the shallow-water tract will remain a mere ribbon. But if, on the other hand, the sea be withdrawn merely to the angle of the sea-shelf the relations between sea and land will be critical and every warping of the surface platform will be decisive either in emphasizing the restrictional influence or in relieving it. To illustrate by a specific case: suppose the sea level to lie accurately at the angle of the ideal sea-shelf, and that portions of the continental platform are warped upward to the amount of 500 feet, while alternating portions are warped downward to an equal amount. The shore line in the former case will lie along the abysmal face and the shallow-water tract will be narrow. In the latter case the shore line will be thrown out upon the upper surface of the sea-shelf and the shallow-water tract will be relatively wide. If the sea-shelf be ideal its upper surface will have a very gentle slope and the downward warping of 500 feet would carry the shore line well inland and give a notable embayment favorable to the perpetration and development of shallow-water life. Under such conditions of alternate warping up and down the continental platform would be bordered by embayments favorable to life, separated by narrow shore tracts which would be largely prohibitive of free migration of shallow-water life between the embayments. Each embayment will there-

fore develop its fauna in measurable independence. Each embayment will become the generating area of a provincial fauna. If now a period of quiescence ensues and systematic continental evolution proceeds, these embayments will become extended landward and grow into extensive epicontinental gulfs and perhaps at length into broad epicontinental seas, and their faunas will expand accordingly. In the progress of this development they may come into conjunction with each other and a commingling and conflict of faunas ensue, resulting in the evolution of a new assemblage of life of a composite type.

Whether the internal progression reaches this stage or not, the development of the sea-shelves must at length attain a stage such that coastal migration will become free and the faunas of the embayments become commingled by coastwise extension. The ideal result of this line of progression is the evolution at length of a general fauna of the expansional type and the concurrent elimination or fusion of the provincial features, for the line of progress is essentially expansional, and the result is expansional evolution. It differs only from an expansional evolution starting from a general restrictional evolution in the commingling and conflict of well-differentiated faunas resulting from provincial development.

At the close of the Silurian period the sea appears to have been drawn away from the land into the critical attitude here indicated, and the basin of the St. Lawrence Gulf and probably that of Hudson's Bay and perhaps other embayments on the borders of the continent, appear to have furnished refuges for the retiring fauna of the Silurian period, and to have become areas in which the origination of provincial faunas took place. The consecutive series of sediments of the St. Lawrence embayment, though not yet perfectly investigated, give good grounds for the belief that the transition of the Silurian fauna into the Helderberg fauna took place there. After its provincial character had been fully assumed and the re-advance of the sea opened the way into the interior through the Champlain tract, it reinvaded the interior basin and left its record as a distinctive

fauna. It was followed in succession by the invasion of the Oriskany fauna, whose place of origin is less clear, but which followed the Helderberg track; by the Corniferous fauna, apparently from the Hudson's Bay embayment; by the early Hamilton fauna, apparently from some southern embayment; and by the later Hamilton fauna, apparently from the Mackenzie embayment, or beyond, thus giving to the Devonian period a distinctive aspect as a time of successive invasions of provincial faunas generated in embayments about the borders of the continent.[1] Had the waters been withdrawn so far as to have emptied these embayments, as was apparently the case at the close of the Palæozoic era, a general repressional evolution would have taken the place of this pronounced provincial evolution. The determinative element, therefore, seems to have been *the critical attitude of the sea to the land* which gave maximum effect to the inequalities of its border.

It is obvious that any previous warping of the continental platform by which a portion of it is submerged may give rise to an embayment covered by relatively shallow water at times of the ocean's withdrawal, and that this may become a refuge for the retreating faunas, and may break the force of the general repressional evolution which would otherwise ensue. This may take place even when the seas are withdrawn down to a level much below the critical horizon just discussed. Such embayments may be regarded as adventitious, since they are not the product of the systematic actions here discussed. But such adventitious embayments were probably always present at times of great withdrawals of the sea, and so broke the force of repressional evolution. In the withdrawal of the sea at the close of the Palæozoic era, the Mediterranean basin appears to have afforded such a retreat for the hard-pressed Permian life of the western part of the Eurasian continent, and to have become a transitional tract in which originated one of the three or four great provincial faunas that advanced upon the land in the Triassic and Jurassic periods. A similar great embayment appears to have existed in

[1] Drawn mainly from the studies of H. S. Williams and Stuart Weller.

the upper Indus and Ganges basins, involving the site of the present Himalayas, and this appears to have been preëminently a transition tract from the Palæozoic to the Mesozoic eras.[1] The adventitious factor in such cases becomes a saving clause so far as the efficient preservation of remnants of the previous fauna is concerned. But even the adventitious factors receive their importance from their critical relations to the systematic attitudes of land and sea upon which chiefly depend the great lines of progress of marine life.

T. C. CHAMBERLIN.

[1] GRIESBACH, Mem. Geol. Surv. India, Vol. XVIII, pp. 1–232, 1891.

THE INFLUENCE OF GREAT EPOCHS OF LIMESTONE FORMATION UPON THE CONSTITUTION OF THE ATMOSPHERE.

THE virtues of carbon dioxide are in inverse ratio to the sinister reputation which "a little knowledge" and a narrow homocentric point of view have given it. As a constituent of the atmosphere it is as necessary to the maintenance of life as oxygen because it is the food of plants and they in turn are the food of animals. Its peculiar competency to retain the heat of the sun renders it a decisive factor in the maintenance of that measurable constancy and geniality of temperature upon which the existence of life depends. It is a leading agency in the disintegration of crystalline rock and is a necessary factor in other geologic changes. It is an essential link in a chain of vital processes which involve all the constituents of the atmosphere. Inherently it may be no more necessary to these processes, save in its thermal nature, than is oxygen, but being the *minimum* factor in the atmosphere it becomes regulative and decisive, because variations in it affect the whole cycle of processes dependent on it, while similar variations in the major constituents may have no appreciable effect. It is the *least* chemical constituent of a mixture that determines the amount of reaction. A loss of nitrogen or oxygen equal to .0003 of the atmosphere would doubtless be wholly inconsequential, while that amount of loss of carbon dioxide would be fatal to life and to many important geologic processes. Oxygen would doubtless become the critical factor if geologic processes in the aggregate consumed it more rapidly than they do carbonic acid. But the reverse seems to be the case now, and it has quite certainly been the case throughout the determinable portion of geologic history. This becomes equally apparent whether we approach the question in the order of the actual processes or the reverse.

Taking the average constitution of the crystalline rocks as a basis, even a rude inspection shows that the consumption of carbon dioxide involved in their decomposition far surpasses the consumption of oxygen.[1] Or, reversing the mode, an estimate of the amounts of carbon dioxide and of oxygen respectively, which would be freed from the sedimentary deposits of the earth if they were again reduced to the condition of silicates analogous to their primitive state shows a like excess of carbon dioxide. From these considerations, which do not need to be given numerical expression, it will be apparent that carbon dioxide has suffered much more consumption in the progress of the geologic ages than has oxygen. That its consumption has surpassed that of nitrogen is too obvious to require argument.

Whatever the original quantitative relations of the atmospheric constituents, the effect of geologic processes has been their reduction to a quantitative order which is inverse to their functional activity. There is hence a preponderance of the inert and relatively non-participant nitrogen, a medium amount of the more active oxygen, and a minimum amount of the most participant element, carbon dioxide.

Now as the activities of the atmospheric constituents are in many respects connected with each other and mutually dependent, it is obvious that the factor which is at once minimum in quantity and maximum in participation must necessarily be the critical factor of the atmosphere. It is not too much to say that the whole order of vital procedure is hung preëminently upon the function of carbon dioxide as the decisive factor, and it is scarcely too much to say the same of many of the most important of inorganic processes.

The chief reservoir of available carbon dioxide on the sur-

[1] The amount of carbon dioxide which crystalline rocks hold in their microscopic cavities, recently shown by Tilden to be considerable, is only a small fraction of what is required for the carbonation of the rock containing it, on the average. We cannot look to this as a source of enrichment of the atmosphere so far as the superficial rocks which undergo chemical decomposition are concerned, though it may be an important source of enrichment when freed from the deeper rocks by the processes of vulcanism and by other means.

face of the earth is not, however, the atmosphere but the ocean. Reservoir in the ulterior sense is not meant, but in the immediately available sense. I entertain the hypothesis that the interior of the earth is the chief terrestrial reservoir of carbon dioxide in the ulterior sense, and that it is a leading source of secular supply. If Tilden's recent analyses of the carbon dioxide stored in the microscopic pores of rocks, or otherwise occluded within them, be representative of the whole interior of the earth, the total mass of carbon dioxide stored within is something prodigious.[1] To how great an extent this is given forth from age to age and becomes a source of atmospheric supply cannot be determined from present data, but I am fully persuaded that the subject is one of the most vital which now invites investigation. The possible feeding of the atmosphere from cosmic sources also invites definite inquiry. But these are ulterior sources of supply of a secular nature and lie apart from the immediate question here discussed. This incidental mention may serve to definitely set them aside and to forestall misunderstanding.

For the purposes of this paper it is assumed that the constituents of the atmosphere and of the ocean have been essentially the same as at present, and no ulterior source of supply or of loss is taken into account. The endeavor here is merely to trace the effects of a great epoch of limestone formation upon such an atmosphere as we now have, attended by an ocean similar to the present one, and with land relations such as accompany great limestone-forming epochs and their antitheses.

A computation of the approximate amount of available carbon dioxide in the present ocean, based upon the observations of the Challenger Expedition as elaborated by Dittmar, shows a content of about eighteen times that contained in the present atmosphere. This embraces only the carbon dioxide held in the two states familiarly known as "free" and "loose;" that is, (1) carbon dioxide which is simply held in solution, and

[1] On the Gases enclosed in Crystalline Rocks and Minerals. By W. A. Tilden. Chemical News, April 9, 1897.

(2) that which constitutes the second equivalent of the bicarbonates—essentially the bicarbonate of lime. The estimate does not include the carbon dioxide which is united with the basic oxides to form monocarbonates and which may be said to be fixed. To put the matter in another form, only that carbon dioxide enters into the computation which separates from the sea water upon evaporation.

According to the old method of interpreting analyses the carbonate of lime present in sea water should all be bicarbonate. It appears, however, from Dittmar's investigations that the amount of "loose" carbon dioxide in the ocean is only about one-half what would be required if all the carbonate of lime (interpreted under the old system) were bicarbonate. The proportions are about as though the lime existed in the state of a sesquicarbonate—a compound of doubtful existence. Under modern methods of interpretation this lower proportion is theoretically explicable, for each of the basic oxides in the sea water enters transiently into combination with each of the acids, and a larger proportion of monocarbonates is thus consistent with solubility, and, in addition, free ions of both oxides and acids are concurrently present. Under this system of interpretation the proportion of carbon dioxide necessary to maintain the lime in a state of solution is reduced. In accordance with these direct determinations it will be assumed in the discussion that the "loose" equivalent of carbon dioxide is only half the amount necessary to render the carbonate of lime a bicarbonate. It is by no means certain that under the conditions of an atmosphere rich in carbon dioxide the amount would not reach the full second equivalent required by the old chemical philosophy, but the more conservative basis serves equally well the purposes of this discussion.[1]

Data are lacking for more than a very rude approximation to the amount of free carbon dioxide held in simple solution in the ocean, but such data as are available seem to indicate that it

[1] The elaborate investigations of Treadwell and Renter (Zeitsch. Anorg. XVII, p. 170) indicate that the lime is essentially bicarbonate so far as it is carbonate at all.

probably does not exceed two or three times the amount held in the atmosphere. If we assume these figures to be approximately correct there remains, in a semi-fixed or loose condition, carbon dioxide to the amount of fifteen or sixteen times the present normal content of the atmosphere. This large reserve of carbon dioxide is the radical factor in this discussion.

Let a status of land and water and of atmosphere and ocean, such as now exist, be assumed. Since a certain amount of carbon dioxide is associated with the monocarbonate of lime in solution as the second or bicarbonating equivalent, and since the secretion and deposition of the lime takes place as the monocarbonate, the associated carbon dioxide is set free. The deposition of limestone is, therefore, a process of conversion of semi-fixed carbon dioxide into free carbon dioxide. This free carbon dioxide under the law of diffusion distributes itself through the ocean and the atmosphere according to the demands of tensional equilibrium. The ocean and the atmosphere are thereby alike enriched in carbonic acid. If this process were continued without reciprocal action of the opposite kind, the ocean would in time be exhausted of its calcium bicarbonate and the semi-fixed factor would all become free.

But as elsewhere urged[1] the disintegration of crystalline rock through the agency of the atmosphere consumes carbon dioxide in the carbonation of the alkalis and alkaline earths contained in them.[2] In particular, the calcium silicates of the crystalline rocks become calcium bicarbonate and are in part carried in solution down to the ocean. Over against the liberating function of lime-deposition, therefore, there is set this reciprocal process of fixation. Over against the enrichment of the atmosphere in carbon dioxide due to the former there is a depletion due to the latter. Now if these two processes were in perfect balance, a static condition of the atmosphere, so far as these factors are concerned, would be maintained. It is, however,

[1] A Group of Hypotheses Bearing on Climatic Changes, JOUR. GEOL., Vol. V, No. 7, October–November, 1897.

[2] The organic cycle and other processes affect the supply and loss of carbonic acid concurrently, but they are purposely omitted here for simplicity's sake.

beyond reason and beyond geological evidence to suppose that these are habitually in perfect or even in approximate balance, for at certain stages the exposure of the land has been large and its elevation high and the process of rock disintegration and carbonation has been notably favored. Coincident with this the ocean has at such times been extensively withdrawn from the continental platforms and the previous expanse of lime-depositing areas thereby greatly circumscribed. In addition to this, the rejuvenation of the streams has at such times brought into the ocean exceptional amounts of detritus and rendered the coasts uncongenial to many of the limestone-forming organisms. It is probable also that even the pelagic calcareous organisms have been at such times adversely affected directly or indirectly by these conditions. On the other hand there have been times when the sea crept out over great areas of the continental platforms and afforded vast expanses of shallow water congenial to the maintenance of lime-depositing life. There is direct palæontological and physical evidence that such extensive epicontinental seas were spread upon the eastern and western continents at the same time, as for example, in the Ordovician, the Silurian, the Carboniferous, and the Cretaceous periods. Geological evidence compels us likewise to recognize recurrent fluctuations in the prevalence of such limestone deposition, intermittent with the antithetical process of land degradation.

Returning now to our selected case based on the present status of atmosphere, ocean, land, and water, we may safely assume that one or the other of the two alternatives, the fixation of carbon dioxide, or the freeing of carbon dioxide, is at present preponderant. Either the carbonic consumption upon the land is in excess of the carbonic freeing in the ocean, or the reverse is the case; if not so momentarily, at least so habitually.

Let us assume, in accordance with the probable fact, that the disintegration of the silicates is now exhausting the carbonic acid of the atmosphere faster than the deposition of limestone eliminates it, and that, therefore, the calcium bicarbonate in the ocean is increasing. The result of this process if prolonged

without interference would be the exhaustion of the carbonic acid of the atmosphere, and, incidentally, the lowering of the surface temperature through the withdrawal of the heat-conserving influence of the carbon dioxide, the reduction of the moisture of the atmosphere through the decline of the temperature, the checking of the vegetal growth, and if the process were to proceed to its extreme, the destruction of vegetal life, and of animal life as well. There would also be concurrent diminution of the chemical disintegration of the rock because of the lessened supply of the disintegrating agency, carbon dioxide, and because of the reduction of the auxiliary agencies, warmth, moisture and vegetation. Theoretically, rock disaggregation by physical agencies might grow into relative preponderance over chemical disintegration, since it would be aided by the sharp oscillations of temperature which would follow the withdrawal of the equalizing blanket of carbon dioxide and aqueous vapor. In such a case the land detritus from crystalline areas would constitute arkose deposits which stand in genetic contradistinction to the limestones, mudstones, and sandstones, which are the result of chemical disintegration through the preponderant agencies of carbonic acid and water. Whether this is really the explanation of the arkose deposits that occur at certain geological horizons is not here seriously considered. The assumed procedure is simply carried to its logical extreme. Arkose deposits may certainly be made locally under present conditions.

But the process cannot reasonably be supposed, under current conditions, to go to the ultimate extreme of destroying all life and subjecting the nude surface to mechanical disaggregation; for the process is self-checking. With the reduction of the carbon dioxide in the air, the rate of consumption is decreased as just indicated. At the same time the ocean is being enriched by the calcium bicarbonate carried down by the land waters, and the conditions there rendered more favorable for the formation of limestone and, through it, for the freeing of the second equivalent of carbonic acid. Even if the rate of freeing this

carbonic acid were reduced temporarily by the indirect adverse influences springing from the impoverishment of the life on the land, the continued reduction of the rate of consumption of carbonic acid on the land must cause it at length to fall below the freeing action in the sea, and the impoverishment of the atmosphere give place to enrichment which would run its course until the preponderance of action was again reversed.

But another element of vital importance enters the problem, the changing attitude of the land and the sea. Such changes may be systematic or adventitious. If they are adventitious the results are beyond easy discussion, but adventitious changes are believed to be subordinate to the systematic changes, since these latter follow (1) from coördinate movements of the earth's crust; (2) from uncoördinate movements of the crust which the ocean coördinates by its leveling function, and (3) from no movements at all. The last is the simplest and most representative case.

Let there be no essential movement of the crust for a prolonged period. That this has been an actual case repeatedly, the base levels of different periods testify. During such a period the height and the area of the land are both diminished. The rate of disintegration of the rocks is consequently reduced, and, concurrently, the rate of impoverishment of the atmosphere in respect to carbonic acid and of the conveyance of calcium bicarbonate to the ocean[1] is also diminished. At the same time the edge of the sea is advancing upon the borders of the land, partly by erosion, partly by the lifting of the sea level by the reception of sediments, and partly, perhaps, by the quasi-fluent creep of the continent toward isostatic equilibrium.[2] This results in the extension of the sea shelf and possibly in the formation of interior epicontinental seas, as exemplified notably in the central epochs of the Ordovician, Silurian, Devonian, Carboniferous, and Cretaceous periods. This extended sea shelf and these epi-

[1] The Ulterior Basis for the Classification of Geologic Time Divisions. JOUR. GEOL., Vol. VI, No. 5, 1898.

[2] Loc. cit.

continental seas furnish conditions congenial to the chief lime-secreting organisms. Preëminently is this true when approximate base leveling attends the wide transgression of the sea, as it normally does, since the two conditions are cogenetic. At such times the waters are relatively free from land wash, and the extended shelves and the epicontinental seas have their greatest availabilities of depth. These are the conditions theoretically most favorable to limestone formation. These seem to be the conditions that actually prevailed at the epochs of great limestone deposition. At such periods great quantities of carbonic acid previously stored in the calcium bicarbonate of the ocean were set free and the atmosphere enriched in carbon dioxide. It was precisely during such periods of special enrichment that the land was most incompetent to impoverish the atmosphere, because it was then smallest and lowest. During the prevalence of these conditions it seems inevitable that the enrichment of the atmosphere should have become notable. A rude computation may give some impression of the quantitative competency of a great deposition of limestone to set carbonic acid free. The limestones of the mid-Ordovician period may be taken as an example. According to the estimate of Dr. Tillo,[1] 17 per cent. of the land is covered by the Palæozoic series and 80 per cent. by the total sedimentary series. Taking no account of the loss by erosion, nor of the portions concealed by the ocean, and making the very conservative assumption that only one-fourth of the sedimentary area is underlain by this wide-spreading formation, and the further excessively conservative assumption that the Ordovician limestones average only fifty feet exclusive of impurities, and that only a half equivalent of carbon dioxide was freed for every equivalent of calcium carbonate extracted from the sea water, we still find the amount of carbon dioxide set free to be sixty times the present carbon dioxide of the atmosphere. It is obvious that this amount could not be extracted from an ocean like the present one without concurrent supply, for it is about four times as great as the ocean's avail-

[1] BERGHAUS' Physical Atlas. Introduction to Geological Maps.

able content. It seems apparent that a process which sets free carbon dioxide in so large a proportion to the total atmospheric content would be competent to vary that content notably, if, as contended, the process is subject to notable variations, and especially if, as also contended, the reciprocating process of fixation varies coincidentally with it so that the two mutually intensify each other's effects.

Dr. Arrhenius[1] has estimated that the addition of two or three times the present amount of carbonic acid to the atmosphere would give the genial climate in the arctic regions which the Tertiary flora indicates. Even if this estimate should be much too small, it would not seem to be beyond the competency of a great limestone-making epoch to enrich the atmosphere in carbonic acid sufficiently to thermally blanket the earth effectively and to so retain, distribute, and equalize the temperature as to render all latitudes available to vegetal and animal life. The notable feature connected with the extension of life to the high latitudes is the marvelous equalization of temperature. White and Schuchert[2] have recently given great emphasis to this by showing that in the Potomac epoch an almost identical flora flourished in north Greenland and in Virginia. A simple increase of solar heat, distributed as it is today, does not meet the demands of the problem. An equalizing and distributing factor seems to be indicated. And this, eminent physicists from Tyndall to Arrhenius encourage us to believe may be found in a change of the atmospheric constitution in the critical item of carbon dioxide, a change of no excessive amount and without serious variation in other constituents, except as they follow from this incidentally.

If the freeing of carbonic acid incident to limestone deposition were a potential factor in the equalization and amelioration of climate which permitted the extension of warm-temperate life to high latitudes, such extension should be coincident with the great limestone-forming epochs. Such appears to be the

[1] Phil. Mag., S. 5. Vol. XLI, No. 251, April 1896, pp. 237–279.

[2] Bull. Geol. Soc. Am., Vol. IX, pp. 343–368.

testimony of geological history. It was in the Middle Ordovician, the Middle Silurian, the Middle Carboniferous, the Middle Cretaceous and the early Tertiary that life of the warm temperate types prevailed in the arctic lands. And these seem to be periods of base leveling and of wide incursions of lime-depositing seas. It cannot at present be asserted, on the other hand, that there were intervening periods when warm temperate life did not prevail there, and could not because of low temperature. In the very nature of the hypothesis here entertained, such periods would be coincident with relative land elevation, and their record would be absent, or so obscurely indicated that only critical investigation directed to the point could detect it.

But in the lower latitudes we find evidence of aridity and of cold temperatures intervening between at least some of the periods of extensive limestone formation, as, for example, the saline deposits which took place between the great limestone-forming epoch of the mid-Silurian period and the similar epoch of the Devonian; or, again, the saline and gypsum deposits and red sediments of the Permian and Triassic age between the limestone epoch of the Carboniferous and that of the Jurassic. In this gap also falls perhaps the glaciation of India, Australia, and South Africa. The Pleistocene glaciation and the measurable aridity of recent times, falling between the limestone-forming epoch of the early Tertiary and a possible limestone-forming epoch of the future which should theoretically follow upon the degradation of the continents, if crust movements remain in abeyance, may form another example.

In considering the antithetical epochs where limestone formation is at a minimum, and rock disintegration is at a maximum, it may be noted that at the close of the lime-depositing epoch the ocean is low in calcium bicarbonate and rich in carbonic acid, and is not then predisposed to deposit lime chemically, but is, on the other hand, in a condition to receive and hold the calcium bicarbonate sent down from the land. When, therefore, an epoch of special earth shrinkage and of readjustment to accumulated stress ensues, and the ocean is more fully drawn into the

deepened basins and the land exposed and incidentally corrugated, the conditions for the reversal of the atmospheric change are propitious.

If a computation be made of the amount of carbon dioxide that would be required to disintegrate the crystalline rock requisite to supply the clastic material for a great epoch of sandstone and shale deposition (allowing duly for old clastics used over), a competency to exhaust many atmospheric equivalents of carbonic acid will be shown. This, being correlated with limited limestone formation, and consequent scant returns of carbonic acid from the ocean, seems competent on its side to notably change the constitution of the atmosphere in the direction of poverty of carbonic acid.

The effect of the limestone-depositing epochs upon the atmospheric oxygen and nitrogen has been ignored for simplicity. While doubtless important, the process does not seem to have any such potential consequences as those which attend the decisive and regulative factor carbon dioxide. Its discussion will therefore not be undertaken here.

The action of intercurrent agencies has been purposely ignored. Some of these are quite obvious. The organic cycle of carbonic acid consumption and oxygen liberation by plants, and of carbonic acid production and oxygen consumption by animals, and the coördinate fixation and freeing of nitrogen alternately, was an ever present factor, and contributed in its own way to a constitutional change of the atmosphere. Although the cycle is measurably self-supporting, it is not a solution of the problem of perpetual motion, and the total result for a protracted period is a permanent alteration of the ratios and of the absolute amounts of the constituents of the atmosphere. But the discussion of this is reserved.

The periodicity of epochs of great limestone-formation reciprocating with epochs of great land extension has been assumed on the basis of a recent discussion.[1] That there were intervening

[1] The Ulterior Basis of Time Divisions and the Classification of Geological History. This magazine, previous number, pp. 449–462.

epochs when neither the one nor the other were greatly preponderant is not only not questioned, but will, in a separate article, be urged as the special agency of an important function in biological, as well as geological, progress.

Other limitations will suggest themselves, as the change of calcium carbonate into calcium sulphate, and the reverse, in the sea or in the course of organic processes, but it is believed that none of them radically affect the particular function herein assigned to great epochs of limestone formation.

T. C. CHAMBERLIN.

STUDIES FOR STUDENTS.

THE DEVELOPMENT AND GEOLOGICAL RELATIONS OF THE VERTEBRATES.

III. REPTILIA. — (*Continued.*)

THERIODONTA. — This name is applied to what must be considered as a very unstable order of the reptilia. Composed as it is of the least well understood of the reptilian forms, it may at any time fall asunder under the light of new discoveries and be seen to be composed of several well defined orders instead of being a single one. The animals making up the order were originally placed by Owen in his *Anomodontia*, in the family *Cynodontia*, but were soon taken out and placed in a separate order, the *Theriodonta*. Owen's classification was arranged on the forms from South Africa only, and it was soon found that it would not suit the forms from America and Russia. Many schemes have been proposed to accommodate all of the different groups, but none has been arranged as yet that is at all satisfactory; there seems to be a general recognition of three distinct groups, but the value of these is a matter of much dispute. Lydekker, in his catalogue of the reptiles of the British Museum, would call the *Theriodonta* a suborder of the order *Anomodontia*, while Seeley, of the same institution and on the evidence of the same material, raises many forms that Lydekker regarded as families into separate and distinct orders. A quite common opinion among palæontologists, and one that may be of the greatest service to the student, is to regard the *Theriodonta* as an order and the three separate groups as suborders — the *Pelycosauria*, the *Cynodontia*, and the *Gomphodontia*.

The first of these the *Pelycosauria*, is represented most largely in the Permian deposits of the United States, but a few isolated

specimens have been found in the same horizon in Bohemia. They were in some respects of the most primitive type; the skull retained the two post-orbital arches, the teeth were simple in structure and without tubercles or basal band; the vertebræ were deeply bi-concave and pierced for the passage of the notochord; intercentra were present, and the sacrum was formed of two or three vertebræ. Not only were they the most primitive members of their order, but they were among the earliest of the land-living vertebrates after the *Amphibia*, and it is very interesting to note among their characters certain features that clearly foreshadow the culminating point of the order, the mammalia. Such characters are the great flattening of the quadrate bone and the partial surrounding of this element by the temporal bones of the skull, and the beginning of a differentiation of the teeth into specialized regions.

Dimetrodon, from the Permian of Texas, is the best known member of the suborder. There were two post-temporal arches, and the bones of the temporal region were all separate. The eyes were very large, almost perfectly round, and placed far back in the skull. The skull itself was abruptly terminated behind, and extended forward as a strong and rather high nose. The upper jaw was slightly convex on the alveolar border, and was armed with many strong, conical teeth that curved slightly to the rear; there were about three incisors in the jaw, the posterior or outer one being much larger than the others. Behind these came a considerable interval, marked by a deep notch at the junction of the premaxillaries and the maxillaries. Posterior to this came one or two very large teeth in the position of canines, followed by a long series of small conical, slightly recurved teeth of nearly equal size. The alveolar border of the lower jaw was concave to correspond to the curve of the upper, and there were two or three large teeth corresponding in position to the canines of the upper jaw. The surface of the palate and the pterygoid bones were covered by rows of small teeth. The quadrate was much depressed, and only appeared for a very small space on the side of the skull, being nearly covered by the adjoining bones. The

lower surface of the quadrate shows two parallel notches that accommodated a double condyle on the lower jaw. This absolutely prevented any lateral movement of the jaws in mastication. Not the least peculiar thing about the animal was the enormous extension of the neural processes of the spine; these were long and slender, becoming nearly as thin as a whiplash at the upper extremity. They sometimes reached a length of nearly three feet, as much as twenty-eight times the greatest diameter of the supporting vertebra. The limbs were short and stout, but from the location of the articular surfaces it seems that the legs were permanently bent, and that the animal could not raise itself from the ground. It is probable that it dragged itself along after the manner of the crocodiles. It is difficult to say what the appearance of the animal may have been. It is pretty certain that the immensely tall spines were clothed with at least a thin covering of muscle and skin, and then there would have been simply a tall dorsal fin that extended the whole length of the body. The tail of the animal was long, and the feet were strong and provided with claws. The whole brute could not have been less than eight or nine feet long.

Clepsydrops is a much smaller genus, known from the Permian of eastern Illinois and Texas. In general features it does not differ from *Dimetrodon* as far as the skeleton is known. It did not exceed a length of two or three feet.

Naosaurus can be told from *Dimetrodon* by the fact that the spines are not only elevated far above the bodies of the vertebræ, but are supplied with cross-bars like the spars of a full-rigged ship. The spines are larger and heavier than in either of the preceding genera, and are marked with shallow grooves that indicate the position of blood vessels, showing that they were covered with a layer of muscle of some thickness. Besides its occurrence in the Permian (Wichita division) beds of Texas, this genus is known from the Permian (Gaskohle) of Bohemia. The specimens from the latter locality indicate a smaller form, about two or three feet long, while the Texas specimens belong to animals nearly or quite as large as *Dimetrodon*.

The habits of these animals are a matter of great doubt. That they were very pugnacious, is well shown by the frequent fractures in the long and slender spines, which must have suffered severely when the animal got into a fight. They were carnivorous in diet.

From the Permian rocks of Russia come some very imperfectly known forms that seem to belong to this group. These are the fragmentary remains of animals discovered for the most part in working the copper mines on the west flank of the Ural Mountains in the provinces of Kasan and Orenburg in the old government of Perm. The remains are almost entirely from the upper layers of the Permian. They did not have the greatly elongated dorsal spines of the American and Bohemian forms.

Brithopus. — This form was described by Kutorga as early as 1838 from the province of Kasan, from what he then called the Keupfersandstein, now known to be upper Permian. The specimen consists of an imperfect humerus, showing the characters of the *Pelycosauria* and the African forms.

Rhophalodon is from the same region in Russia. It is characterized by the same features of the limb bones as the former genus, but the skull is unusually short and of great vertical extent; so great, indeed, as to give to it an absurdly square outline from the side view. The teeth are much stronger and stouter than those of the American forms, and have a tendency to develop in the lateral direction, giving them a rather broad outline and an appearance very similar to that of the American *Pareiasauria*, the *Diadectidæ*.

Deuterosaurus, from the province of Orenburg, in the same part of Russia, is even more similar to the American forms than the *Rhophalodon*; the skull is almost identical in appearance with that of the genus *Dimetrodon*. It seems strange at first sight to find these closely related forms from such widely separated regions as the United States, Bohemia, and Russia; but if we reflect for a moment that despite the great specialization of the American forms in the dorsal spines, this group is the most

primitive of the land-living reptiles, we may find a reason for the widespread distribution of the group.

The *Cynodontia*. — Under this head is grouped the majority of the South African forms, all except those that by their skull structure approach very nearly to the *Mammalia*. The forms considered here are the ones placed in the families *Galesauridæ* and the *Tapinocephalidæ* by Lydekker, in the catalogue of the fossil reptiles of the British Museum, under the suborder of *Theriodonta*. The group at first glimpse seems very like the *Pelycosauria*, but there is one very important distinction. The two postorbital arches of the first group have disappeared and are replaced by a single one that is either made up of the union of the two primitive ones, or is the single one left after one of them has disappeared; in all probability the first of these cases is the true one. The teeth are of carnivorous type, recurved, and in many cases differentiated into incisors, canines, and molars.

These forms are exclusively from the Karroo formation of South Africa. The position of this formation is not definitely known. It is either Permian or Permo-Triassic. If the evidence of the vertebrate remains is to be taken, it should be placed as far up in the geological time scale as possible, for there are found in these beds remains that are very closely related to forms that are found in the Lower Cretaceous of the United States.

Galesaurus, known from the skull only, was a small, lizardlike animal; the skull was depressed, with a rather long muzzle and very large temporal vacuities. The teeth were differentiated into the incisors, canines, and cheek teeth. The cheek teeth were furnished with small lateral cusps at the base. The whole skull was nearly four inches long.

Aleurosaurus is also known only from the skull. The muzzle is long but quite high, resembling in this respect the nasal portion of *Dimetrodon*. The teeth are simple and without the lateral cusps. There is a single large tusk in the upper jaw in the position of a canine. The posterior part of the skull is abruptly truncated, as in the previous suborder.

Lycosaurus was a larger form, with a skull nearly eight inches long. The upper jaw was very convex on the alveolar border, and the lower jaw was correspondingly concave. The whole skull was much depressed.

Cynognathus.—This genus is in some respects the most nearly related of the *Cynodontia* to the *Pelycosauria*, and in others most closely to the succeeding group, the *Gomphodontia*. The general aspect of the skull is that of the *Pelycosauria*. The cranial region is abruptly terminated; the jaws are curved on the alveolar border, and the teeth are divided into the separate regions. There is, however, only a single temporal arch that is almost certainly made up of the two primitive arches combined. The teeth are cuspidate, with a single tubercle in front and another behind. These are developed on the sides of the tooth as well as on the front and rear giving the first appearance of the tubercular type of the teeth. The palate bones also present a step in advance of the reptilian form. They are extended and unite in the median line, thus forming a separate cavity for the nasal organs. This, however, does not extend very far back, ending at about the middle portion of the roof of the mouth. The occipital condyle is almost double, the two sides being greatly developed at the expense of the median portion. The whole skull of one of the best known species was about fifteen inches long. The vertebræ, pelvis, and limb bones all show the same characters as the preceding group.

Gomphodontia.—The suborder is thus described by Seeley: "The *Gomphodontia* comprises animals with a Theriodont type of dentition, in which the molar teeth are expanded transversely, and have more or less tuberculate crowns of the type shown in *Diademodon*. The superior and inferior teeth are opposed to each other, and the crowns become worn with use, as in the Ungulate and other Mammals, and as in the Iguanodont reptiles. The canine teeth of the upper jaw appear to be worn at the extremities.

"It (the skull) appears to show mammalian proportions and aspect, in the definition of the large temporal vacuities, by a

zygomatic arch, which is formed by the molar and the squamosal bones, and in the separation of those vacuities from each other by a long, narrow, parietal crest. The orbit of the eye, however, is separated from the zygomatic vacuity by a postfrontal bone, so that the structure is distinct from that which obtains in the 'mammals.'

"There are two well-defined occipital condyles at the back of the base of the skull, united to each other inferiorly in a way that is closely paralleled in some mammals. The hard palate formed by the maxillary and palatine plates terminates transversely in the middle length of the molar teeth in a way that is remarkably like the dental condition of certain Marsupial mammals.

"So far as is known, there is no fundamental difference in the skeleton to separate the *Gomphodontia* from the *Cynodontia*, which may be regarded as related in the same way as are groups of the Marsupials with similarly differing dentition."

The group *Gomphodontia*, as the author of the suborder says, does not obliterate the interval between the mammals and the reptiles, but it does close up the gap to a large extent, and we are well able to see what must have been the few final steps that led to the formation of the *Mammalia*. If the quadrate should entirely disappear and the teeth take on ever so little a difference in form, if the bones of the squamosal region should coalesce, as they have almost done already, there would be no place where we could say this is reptile and this is mammal.

The known genera of this suborder are: *Tritylodon*, *Trirachodon*, *Diademodon*, *Gomphognathus* and *Microgomphodon*.

Tritylodon was originally described as a mammal by Owen. It is known only from the imperfect upper portion of the skull. The skull was long and rather narrow; the anterior nares were joined in one external opening; there were no incisor teeth, but a large pair of canines; the molar teeth were broad and supplied with three rows of tubercles; between the canines and the molars there was a long diastema. The specimen is from the Permian of Basutu-land in South Africa. From the same region

Seeley has described the forearm and forefeet of an animal that he called *Theriodesmus* which may belong to *Tritylodon*.

From the upper Triassic of Wurtemberg, near Hohenheim, Fraas has described a single tooth that bears a very striking resemblance to the molar teeth of *Tritylodon*. This tooth he calls *Triglyphus*.

Diademodon is from the eastern part of the Cape region of South Africa; it is known from an imperfect skull showing the palate and the teeth. The characteristic part of the skeleton is the broadly tubercular teeth; they are flat or cupped on the grinding face, with the edges showing many small tubercles; the appearance is not unlike that of the pig or the human tooth.

In other characters than the teeth the genus is very similar to the *Cynodontia*, and the chief point of interest to us is the evidence of a gradual progression towards a more and more complicated style of tuberculate molars that is to culminate in the multituberculate type of the most primitive mammals.

Trirachodon.—Of this genus Seeley says: "The skull in this genus has a most remarkable mammalian aspect, in form and proportion of every part. It was four inches long, as preserved, and about two inches wide behind. The orbits are circular, placed slightly in advance of the middle length of the head. The snout appears to terminate conically, rounded above and tapering forward, with a rounded alveolar margin. . . . . Each molar crown has three transverse, conspicuous ridges, but the middle ridge is the most elevated, and rises as a distinct cusp on the external and on the internal margins."

Microgomphodon.—This genus is known from the portion of a skeleton preserved in a slab of rock from the same region as the preceding genera. The teeth are the most characteristic portion; they are much enlarged in the transverse direction, being nearly or quite as long as wide. The surface is slightly convex from before backwards, and is covered with small tubercles, that become much larger at the external and the internal edges. The form is a small one, the largest teeth having a transverse diameter of two-tenths of an inch only and an antero-posterior

of one-tenth. The ribs are of the usual broad character of the African Permian reptiles generally, and the pelvis shows the broad ischium and pubis of the *Cynodontia*.

Gomphognathus.—This is perhaps the most interesting of the South African reptiles, because of its great similarity in structure to the *mammalia*. This is most apparent in the double occipital condyles, in the length of the separated nasal cavity, in the division of the teeth into premolars and molars, as well as into the major divisions of the dentition, the incisors, canines, and molars. The whole aspect of the skull is strikingly mammalian. The molar teeth have a posterior cusp or heel, and the outer edge is raised into a sharp cusp.

The geological and the geographical relations of this group are of extreme interest. They range in time only through the Permian and the Triassic. They are known only from a very limited region in South Africa, and from an even more limited region in the United States, where indeed the whole range of the fossiliferous beds is within the limits of four counties. Besides these two regions there is the case of the single tooth from the Wurtemberg region.

Dinosauria.—The *Dinosauria*, or the *Dinosaurs*, is the name applied to a large group of extinct animals that were confined to the Mesozoic time exclusively. When the existence of the group was first recognized by Owen, in 1839, he considered it as a well-defined order. Later discoveries have shown that under the original description there must be placed in the order animals of the most diverse character, so that it is becoming apparent that the old group must be abandoned and another, or, more correctly, several others, substituted. The very comprehensive character of the order, as usually defined, may be seen from the following characters given by Marsh, Zittel, Haeckel, and other writers on the group.

Premaxillary bones separate; upper and lower temporal arches present; no teeth on the palate; rami of the lower jaws united by cartilage only; vertebræ procœlus, opisthocœlus, or amphicœlus, sacral vertebræ united; scapula elongate; no pre-

coracoids; coracoid small; ilium greatly prolonged in front of the acetabulum; the ischia joining on the median line below; the pubis often with a strong posterior process, the post-pubic process. The form of the body and the head varies greatly in the different forms, being sometimes like that of the crocodiles and at other times like that of the birds, reptiles, or even the mammals. In the majority of the forms the hind limbs exceeded the anterior ones in size, and were used more commonly in walking; in some of the later and more specialized forms the anterior pair of limbs had lost the ambulatory functions entirely and had become wholly prehensile in character. The feet were as variously developed as the other parts of the body; in some of the forms inclining towards the ungulate type and in others developing well-formed claws. The dentition varied from the carnivorous to the herbivorous, some forms having strong recurved tusks, with serrated anterior and posterior cutting edges, and others with the jaws filled with close-set grinding teeth. The external appearance presented as many differences as the skeleton; in size they varied from that of the great herbivorous forms much larger than an elephant to the little leaping carnivorous forms no larger than a jack-rabbit. The skin of some was smooth and of others thickly covered with bony dermal plates and excrescences. Some walked erect, using the strongly developed tail as an aid in supporting the body, while others were entirely quadrupedal.

This great range of characters has led to a great number of different schemes of classification, in most of which the order *Dinosauria* has been recognized as a definite group, but it is constantly growing more difficult to keep the heterogenous assemblage together. Through all the later attempts at classification there has been a recognition of three types of structure that have been regarded as of ordinal, subordinal, or family rank by the various authors. These three divisions were regarded by Baur as distinct groups having nothing to do with each other.[1]

[1] BAUR, "Remarks on the Reptiles generally called Dinosaurs," American Naturalist, May 1891.

In his last classification of the *Dinosaurs*,[1] Marsh recognizes essentially the same group as Baur, but considers them as orders of the subclass *Dinosauria*. These three groups are called *Theropoda*, *Sauropoda*, and *Predentata;* the same groups were called by Baur *Megalosauria*, *Cetiosauria*, and *Iguanodontia*.

It is without the scope of the present article to discuss the intricate taxonomy of this group, and it will perhaps suffice to recognize the three distinct groups and to know that the tendency at the present is to consider the *Dinosauria* as an unnatural order and to speak of the *Dinosaurs* as a very loosely connected group made up of several distinct and well-defined groups.

THEROPODA (*Megalosauria*). — Brain case incompletely ossified in front; no ossified alisphenoid; an epipterygoid (columella); premaxillaries not excluding maxillaries from the nasal opening; jugal connected with the alveolar border of the maxillaries on the same plane; quadrato-jugal free from the maxillary; quadrate directly backwards; mandible without predentary bone; dentary without coronoid process; sacral vertebræ with the ribs joined intervertebrally; diapophyses of the vertebræ without connection with the ribs, but reaching out to and joining the ilium; pubes directed forward and strongly united at the distal end; limbs with the bones frequently hollow; posterior limbs much the largest; feet terminated by claws that are prehensile in the fore foot; locomotion mainly bipedal and digitigrade.

Anchisaurus, the oldest one of this group, as well as the oldest known *Dinosaur*, is from the Triassic Red Sandstone of the Connecticut Valley. A nearly perfect skeleton was obtained from these rocks in the vicinity of Manchester, Conn., in 1884. Previous to this time there had been fragments of skeletons obtained from the Triassic rocks of Pennsylvania and Prince Edward's Island, in Canada, as well as from the same deposits in the Connecticut Valley that in all probability belong to the same genus.

[1] "The Dinosaurs of North America," 16th Ann. Rept. of the Director of the U. S. G. S., Pt. I.

The skull was very birdlike in general outline; both the upper and lower jaws were full of small, sharp teeth that inclined toward the anterior ends of the jaws, and were not differentiated into molar and incisor regions (this feature occurs only in the most specialized of the reptilia); the fore limbs were much smaller than the hind limbs, but were quite large in comparison with those of the more specialized forms of later time, and perhaps took a large part in walking, although the hind limbs undoubtedly were the most largely used; all the bones of the limbs were hollow, and had very thin and solid walls, as in the birds; the fore foot had five digits, only four of which were functional; the hind limb had four toes on the foot, the fifth being a mere rudiment and the first much smaller than the others, so that the track would have been that of a three-toed animal. It is altogether probable that many, if not all, of the so-called bird tracks of the Connecticut Valley sandstone were made by these animals. One species had a length of nearly six feet, while another was much smaller, no larger than a "small fox."

Thecodontosaurus is one of the few European Triassic *Dinosaurs* that are known. It is from the Rhaetic of Bristol in England. The form is known from teeth and from portions of the skeleton; the teeth are of the typical carnivorous type, and are serrated on the anterior and the posterior borders.

Zanclodon (*Plateosaurus*) is from the Trias of many parts of Germany. The teeth are curved backward as in the preceding genus, and are serrated on the anterior and the posterior edges; the vertebræ are deeply bi-concave, and are very much longer and smaller in the cervical than the dorsal region; the limbs were short and strong and the jaws were long and curved. Only a part of the skeleton is known, although several specimens have been discovered; altogether there are about sixty vertebræ preserved in series, and these have a length of nine feet; the form is remarkable in being one of the few *Dinosaurs* that have bi-concave vertebræ.

Epicampodon is a form from the Trias of the East Indies,

Panchet group. It is known only from a few teeth having the same character as those of the previously described forms.

Massospondylus is the name given to certain remains from the Trias of South Africa, Karroo formation, and East India, Panchet group, that are known from a few teeth of the usual recurved type and some deeply bi-concave vertebræ.

Arctosaurus is from the northern part of North America, and is known only from a single vertebra.

Compsognathus from the upper Triassic of Bavaria, Lithographic Slates of Kelheim, was very similar in many respects to *Hallopus* of the Jurassic; the hind limbs were much smaller than the fore limbs, and the lower part of the leg showed the same adaptation to a leaping form of progression. The bones were all hollow and very compact in structure; the cervical vertebræ were numerous, forming a long neck, to which the head was joined at right angles. The astragalus was very closely joined to the end of the tibia, much as in the birds. Many authors have seen in this form the direct ancestors of the birds, but there are still wanting certain links to join the two forms together.

This closes the list of the well-known Triassic *Dinosaurs*. It will be noticed that they are all of the carnivorous type, though indications of a larger form of the herbivorous type are mentioned by Marsh. This author says of the distribution of the Triassic *Dinosaurs:* "It is a remarkable fact that the seven skeletons of Triassic *Dinosaurs*, now known from the eastern part of this continent, are all carnivorous forms and of small size. There is abundant evidence from large footprints that large herbivorous *Dinosaurs* lived here at the same time, but no bones nor teeth have yet been found. In the western part of the continent a few fragments of a large *Dinosaur* have been found in strata of supposed Triassic age, but with this possible exception osseous remains of these remains appear to be wanting in this horizon." Footprints "have been discovered in the Triassic sandstones of New Mexico. A few bones of a large *Dinosaur* were found by Professor Newberry in strata apparently of this age in southern

Utah. These remains were named by Professor Cope *Dystrophæus.*"

Hallopus, from the Jurassic of Colorado, is remarkable for its development as a leaping form; the femur is much shorter than the fore part of the leg and the metatarsals are greatly elongated, as in the jumping rodents. The whole form was not much larger than a rabbit.

Cœlurus, from the upper Jurassic of Wyoming, was much larger than the preceding genera, being several feet in length. It was of the same jumping type, the fore feet being much the larger. The skull is very imperfectly known. The most remarkable thing about the skeleton is the thinness of the bones and the great cavities that exist in all of them, the ribs even being hollow. The limb bones, the vertebræ, the bones of the pelvis and of the pectoral girdle, are all excavated by large air cavities that must have rendered the skeleton very light. The dentition was of the same carnivorous type as the former genera.

Ceratosaurus, from the upper Jurassic of Colorado, is one of the largest of the *Theropoda*, being about seventeen feet in length. The head was very large in proportion to the body and was quite lizardlike in many respects; there was developed on the anterior portion of the snout a strong bony process that undoubtedly supported a horn during the life of the animal. The bones of the skeleton are very light, having internal cavities such as exist in *Hallopus* and *Cœlurus*, only to a less extent; the hind limb is much larger than the fore limb, so much greater that it is possible that the fore limb was never used for other purposes than those of seizing and holding the prey of the Dinosaur. The bones of the pelvis are anchylosed together, instead of showing the sutures between the bones as in the other forms; this is an essentially birdlike feature.

Allosaurus, *Creosaurus*, and *Labrosaurus* are all from the upper Jurassic of Wyoming and Colorado. The former was one of the largest carnivorous forms of the United States, if not the largest. The total length was about twenty-one feet. Remains that have

been referred by Marsh to these genera have been taken from the Potomac Beds of Maryland.

Lælaps was one of the same type of *Dinosaurs* as those already described It is from the upper Cretaceous of New Jersey and Montana. The animal had a length of about fifteen feet.

The European forms presented scarcely less varied types than the American forms, but the bones are less well preserved and the skeletons consequently less well known. Prominent ones are *Megalosaurus* and *Streptospondylus*. The first, from the Jurassic of England and many parts of the continent, is also known from the Jurassic beds of Colorado and from the Cretaceous of the East Indies. It was one of the largest of the *Theropoda*, the femur being over a meter in length.

Aristosuchus, from the Wealden of England, is somewhat similar to *Cœlurus*, having similar cavernous vertebræ and light limb bones

Tanystrophæus, from the Muschelkalk of Bayreuth, is remarkable for the extremely elongated cervical and caudal vertebræ. They are eight or ten times as long as they are broad, and are hollow as in *Cœlurus*. The same form is known from the Triassic rocks of New Mexico.

SAUROPODA (*Cetiosauria*).— Brain case completely ossified in front; a well developed alisphenoid; no epipterygoid (columella); premaxillaries not excluding the maxillaries from the nasal opening; jugal and quadrate forming a continuation of the posterior border of the maxillary in the same plane; quadratojugal in connection with the maxillary: quadrate directed forward; mandible without predentary bone; dentary without coronoid process; sacral ribs attached to a single vertebra; neural canal much expanded in the sacrum; limb bones without medullary canal; the fore and hind limbs nearly of the same size; feet plantigrade; the termination of the toes in nails or hoofs rather than in claws.

The order is practically unknown in Triassic time, but in the

Jurassic reached a very great development, both in numbers and in diversity of forms.

Brontosaurus is from the upper Jurassic, in the vicinity of Lake Como, in Wyoming. It is the largest *Dinosaur* known, as well as the largest of the animal creation; the whole beast, from tip of snout to tip of tail, measured nearly sixty feet. The head was very small in proportion to the rest of the body, being less than the fourth cervical in size. The tail and the neck were long and quite strong. The tail was over half as long as the rest of the body; the dorsal vertebræ had a short antero-posterior extent, but were quite broad. A hole under the transverse process of each side opened into a large cavity in the body of the vertebra, probably for the purpose of reducing weight. The pectoral girdle is represented by the usual elements, but the coracoid is very much smaller than the scapula and the sternum is composed of two pieces, one on each side of the median line as in the embryos of birds. The neural canal is greatly enlarged in the sacral region; this enlargement begins even in the cervical region, so that it would have been possible to have drawn the whole of the brain down through the neural canal.

It is difficult to see how an animal that had reached the unwieldy size of the *Brontosaurus* could have supplied itself with food; the very small head and rather weak dentition would seem to render the actual task of getting a sufficient supply of food into the enormous body a very difficult one, even granting that the food was most plentiful; but if the animal was compelled to search to any extent for its supplies the work must have been an almost constant one. This is especially true because the food was entirely vegetable, and the proportion of such food necessary to support a body is much greater than the more condensed food of the carnivorous forms. The animal was in all probability semi-aquatic in its habits and lived for a good part of the time in the waters of the oceans and the lakes of the later Jurassic and the early Cretaceous time. That they suffered much from their great bulk is evident from the condition in which the skeletons are found; they are in many cases complete and undisturbed,

showing that the animal was mired down in some hole or on the uddy bank of some body of water.

Camarasaurus (*Atlantosaurus*) was very similar to the preceding, differing in the fact that the sacral and the caudal vertebræ are solid, instead of having the large vacuities that are found in the same bones of the preceding genus and in the vertebræ of the anterior region of this genus. The scapula of one specimen measured one and a half meters, and the femur nearly two. From the Upper Jurassic of Colorado.

Morosaurus, *Allosaurus*, and *Apatosaurus* are all forms that are distinguished by minor characters of the vertebræ, and limbs from the preceding genera. They are all from the same horizon as the preceding, in Wyoming and Colorado.

Cetiosaurus is from the Upper Jurassic of England; the form is so similar to that of the various American forms that Baur has suggested that all the genera from Colorado and Wyoming are possibly the same as the English one. The skeleton is only partially known, the head being missing in all the known specimens. It was nearly thirty-five feet in length, with about the same proportions of the fore and hind limbs, and the vertebræ as *Brontosaurus*.

Ornithopsis, from the Upper Jurassic of England and France is very similar to *Cetiosaurus*, but shows large vacuities in the sides of the dorsal vertebræ.

Diplodocus, from the Upper Jurassic of Colorado and Wyoming, is remarkable for the long cervical and caudal vertebræ. The vertebræ were very light and hollow, those of the sacral region especially. The chevron bones, instead of being simple, with only the single V-shaped branch, were composed of two V-shaped branches that extended forward and back, and were united at the proximal extremities. The jaws were edentulous, except at the anterior ends, and these were supplied with long, slender teeth that were constantly shed and renewed from below, a specimen with as many as seven successive teeth in various stages of development being known.

Titanosaurus is the name given to certain large vertebræ, from

the Middle Cretaceous layers of the East Indies. The same vertebræ have been found in the Cretaceous of England.

A very imperfectly known form, *Aepysaurus*, is found in the Cretaceous of France.

Imperfect remains have been described from Patagonia, *Argyrosaurus* and *Titanosaurus*, and from Madagascar *Bothriospondylus*.

Some teeth and parts of vertebræ have been discovered in the upper part of the Potomac formation of Maryland.

It will be seen that the *Sauropoda*, as far as we know them now, are for the most part confined to the continent of North America. The few forms that are found in the other parts of the world indicate the wide extension of the group, but in these there is no indication of such a degree of specialization as was attained by the North American forms. This continent seems to have been the home of the group and the seat of their greatest development.

PREDENTATA (*Iguanodonta*).— Brain case completely ossified; a well-developed alisphenoid; no epipterygoid (columella); premaxillaries, with a posterior outer process extending between the maxillaries and the nasals, excluding the maxillaries from the nasal openings; jugals fixed to a special process outside of the alveolar process of the maxillaries; posterior border of the maxillaries free, not attached to the jugal or the quadrato-jugal; quadrate directed forward; the anterior end of the mandible furnished with a distinct predentary bone; dentary with a greatly developed coronoid process; sacral vertebræ, with the ribs and the diapophyses attached, and the ribs joined to two vertebræ (intervertebrally); pubis consisting of two branches, the anterior one, ectopubis (pectineal process, prepubis) extending far forward and joined with the one of the opposite side by suture; the posterior one, the entopubis, extending far backward, and lying parallel to the ischium, is well developed in some forms, but in others rudimentary; illium much extended in front of the acetabulum, and also reaching far behind. In some forms of this suborder the fore and hind limbs were of nearly equal size,

while in others the hind limbs were nearly as large in proportion to the front limbs as in the *Theropoda;* the feet were armed, in the majority of cases, with flat claws, or hoofs. The dentition shows that the animals were herbivorous in diet, and the mouth is, in some forms, crowded full of teeth. This group did not develop the enormous size of the preceding group, but sought protection in the development of a bony armature that rendered them, in many cases, safe from the attacks of the carnivorous forms.

Stegosaurus.—The jaws were furnished with teeth in the posterior portion only, the premaxillaries being edentulous and probably covered with a horny beak that served the animal in gathering the plants which formed its food. The teeth were flattened sideways, and the crowns were serrated; the limbs, bones, and the vertebræ were solid; the fore and hind limbs were of the same size; the neural processes of the dorsal vertebræ were quite high, and supported the ribs from near the apex; the feet were plantigrade, and the toes terminated in broad, hooflike claws. The most remarkable thing about the form was the fact that there were developed in the skin of the back and sides great, broad plates of bone that possibly stood up as a median ridge along the back. All the known specimens are from the Upper Jurassic of Colorado and Wyoming.

Camptosaurus, *Laosaurus*, *Dryosaurus*, and *Nanosaurus* are all from the same horizon and the same localities as *Stegosaurus*. They resemble that form in the arrangement of the pelvis, the bones of the skull, and all the essential features of the group, but differ in many external characters. The hind limbs are much larger than the fore limbs, and seem to have monopolized the function of progression; the fore feet are very small, and could only, under peculiar circumstances, have served as organs of locomotion. There were five functional digits on the fore feet and only three on the hind foot, so that the tracks would have been the same as those of a large bird, and it is very probable that the tracks in the Triassic sandstone of the eastern part of the United States may be tracks of these or of related forms,

instead of birds, as originally supposed. The bones are all hollow, and the whole skeleton was very light. There was an almost complete absence of the dermal armor that characterized the *Stegosaurus;* the whole lightness of the skeleton is incompatible with the weight of such a covering, and it is likely that the animals sought safety in flight, where the former genus trusted to the impenetrability of its armor. The largest of the four genera, *Camptosaurus*, was about twenty feet long, and the smallest, *Nanosaurus*, was only three or four. The last genus is the lightest and the most birdlike of all the *Dinosaurs.*

Dystrophæus is the name given by Cope to the incomplete remains of a *Dinosaur* from the Triassic rocks of Utah. There is preserved only the portions of the hind limb but these show that the animal had only three functional digits on the hind foot and that it was closely related to the *Camptosaurus.*

Teeth from the Potomac formation, evidently belonging to this group have been described by Marsh and Leidy as *Priconodon* and *Paleoscincus.*

Euskelosaurus from the South African beds is too incomplete to be definitely placed anywhere, but is generally placed among these forms.

Scelidosaurus is from the lower Lias of Dorsetshire in England. It was very similar in many respects to *Stegosaurus*, having the same quadrupedal locomotion and the same solid form of the bones but the dermal armor was reduced to a single row of small ossicles down the median line of the back. The whole form was nearly twelve feet long.

Agathaumus from the Upper Cretaceous of Wyoming, is one of the most peculiar of this peculiar group of animals; with the same bodily characters of the trunk as the *Stegosaurus*, minus the dermal plates, the interest of the form centers in the enormous development of the protective armature of the skull. The bones of the posterior cranial region were developed as an enormous cape that extended back over the shoulders; around the edges of the cape there was a series of smaller bones. The frontal portion of the superior aspect of the skull was protected by the

development of three large horns, two of these, the largest, projected from the superior edges of the orbital rims, the others from the anterior part of the snout. One skull taken from the Laramie Cretaceous of Converse county Wyoming, was eight feet from the tip of the snout to the tip of the posterior edge of the skull, and weighed, with the matrix of sandstone, 3600 pounds. The teeth were set in a single row in the jaws and were provided with two roots, a rather peculiar condition in the reptiles. The teeth were transverse and presented broad grinding surfaces. The whole body was stout and elephantine in proportions; the skin was undoubtedly furnished with small dermal ossifications spread through its surface. The tail was long and heavy. The animal must have been, according to Marsh, twenty-five feet long and about ten high.

Torosaurus from the same horizon as the last was smaller, but still quite large, as one skull measured five and a half feet across the top. The most remarkable thing about this form was the great posterior development of the capelike portion of the skull. It extended much farther back than in *Agathaumus* and was perforated by two large fontanelles in the posterior part. The whole plate is much thinner than in the other form.

Claosaurus is from the same region as the preceding and bears about the same relation to those forms that *Scelidosaurus* does to *Stegosaurus*, that is, the general characters of the body are the same, but the peculiar specialization has disappeared. This animal developed the posterior limbs at the expense of the anterior ones, as organs of locomotion. Oddly enough the front feet did not assume the function of grasping organs as in the *Theropoda*, which assumed the bipedal form of locomotion, but retained the broad terminal phalanges that indicate the possession of hoofs on the front feet even after they had grown so short that they could not have reached the ground. The hind feet possessed three functional digits as in *Agathaumus*. The mid-dorsal series of vertebræ was strengthened by the presence of many long ossified tendons that extended for some distance on each side of the neural spines. The limb bones were solid.

The whole animal attained a length of about thirty feet and was probably about fifteen high when it stood erect.

Hadrosaurus is from the same region as all the forms just described and presents the peculiar feature of a flattened snout, resembling the bill of a duck, or the snout of the Australian mammal, *Ornithorhynchus*. Only the skull is well known. The anterior ends of the jaws were edentulous, and were probably covered by a horny sheath; the posterior portions were filled with a large number of teeth that were disposed in rows, and were successional in arrangement so that as fast as the old teeth were worn out new ones, developed in the sides of the jaw, came in to take their places. In one specimen Cope counted six hundred and thirty teeth on each side of the upper jaw and four hundred and six on each side of the lower jaw, making a total of two thousand and seventy-two. The animal was probably aquatic in its habits of feeding, and used the ducklike bill much as the bottom feeding aquatic birds do in gathering up the ooze and slime that contain their food. The fragments of the skeleton that are known indicate that the animal had the same relative proportions of the fore and hind limbs as *Claosaurus*.

Agathaumus, most generally, but erroneously, called *Triceratops*, *Torosaurus*, *Claosaurus*, and *Hadrosaurus* are all from the Upper Cretaceous, the Laramie, and from a very limited region in the northeastern portion of Converse county in Wyoming. A few remains of these forms have been found in near-by portions of Wyoming and Montana.

Iguanodon is the European representative of the *Predentata*. It is one of the few members of the group found outside of the United States. It was of the bipedal type, the hind feet being larger than the fore feet and the whole hind limb showing the more robust character so common in the American forms. There were three functional toes on the hind foot and three on the fore foot, but there were two, the first and the fifth, on the fore foot that are entirely lacking on the hind foot. The first digit on the fore foot was modified in a most peculiar manner into a short and strong spurlike process that stood out at right angles to

the rest of the digits. The vertebral column was strong with well developed neural processes on the dorsal vertebræ which were further strengthened by ossified tendons that aided in moving the heavy tail. The postpubis was long and extended back almost to the distal extremity of the ischium. The teeth were of the same type as the American forms, broad laterally, with serrated edges, and adapted to the trituration of vegetable food. There was no dermal armor as far as known but it is possible that there were small bony ossicles developed in the skin. The animal reached a length of thirty feet in the largest genus and about half of that in the smallest. It is known from the Wealden of England and France, the most important deposit, however, is from the same horizon in the neighborhood of Bernissart, in Belgium, from which region a large number of skeletons have been taken, the majority of them in a very perfect state of preservation.

A description of the *Dinosaurs* would not be complete without some mention of the fossil tracks in the Triassic sandstones of the eastern part of the United States. These are typically developed in the rocks of the Newark group in the valley of the Connecticut River, and are also found in these same rocks where they appear in Pennsylvania, Virginia, and North Carolina. A very large number of these impressions have been taken from the Connecticut region, and over a hundred separate species have been named from them. They are almost all three-toed forms and range from about an inch in length to over a foot. They are found associated with amphibian tracks. The course of the tracks may, in some instances, be traced for many feet or yards, and the length of stride and the character of the feet of the two sides can be clearly made out. The majority of the impressions show that the animals walked on the hind feet most of the time, only occasional traces of the front feet being found. In some cases a long groovelike track indicates where the tail of the animal was dragged through the mud. Because of the three-toed character of the tracks and the peculiar resemblance to the tracks of birds they were originally described by Hitchcock as bird tracks (*Ornithichnites*).

Translating very freely from Zittel's *Handbuch*, we have the following summary of the range and distribution of the *Dinosaurs:*

In general we may say that Europe and North America were, during the Triassic, Jurassic, and Cretaceous times, the home and the region of the greatest development of the *Dinosaurs*. From the East Indies only incomplete remains are known from the Trias and the Cretaceous, and from South Africa, only enough remains to say that there were *Dinosaurs* there. In South America and Australia the remains of these animals are, as yet, completely unknown.

Although the largest number of forms as well as the most perfectly preserved remains are known from the United States, Europe affords many specimens of all the principal groups. The American *Sauropoda* are represented in Europe by *Cetiosaurus, Ornithopsis* and an incompletely preserved Cretaceous form. The *Zanclodontidæ* parallel to some extent the *Anchisauria*. The *Megalosauria* of Europe are represented in this country by *Allosaurus, Lælaps*, and several less well-known forms. The *Ceratosauria* are unknown in the Old World, and the *Cœluria*, hollow-boned forms, are represented by *Calamospondylus* and *Aristosuchus*. *Tanystrophæus* belongs to both the Old and the New Worlds. The European *Compsognathus* is found in the *Hallopus*. Among the *Predentata* the *Scelidosauria* are confined to Europe while the *Stegosauria* are mostly American. *Omosaurus*, if not a synonym of *Stegosaurus*, would be a European representative of this group. The forms from the Laramie Cretaceous are all confined to the American continent.

From a geological standpoint the original distribution of the *Dinosaurs* was practically contemporaneous, though even in the Trias there were well defined areas containing differentiated forms, and this differentiation by local development was accentuated in the Jurassic and Cretaceous. Animals from the two continents frequently belong to the same families but seldom to the same genera and species.

Perhaps the most peculiar thing about these forms is the sudden and complete destruction of the whole order at the end of the Mesozoic time. The Cretaceous rocks just at the end of the period show that there was a very large number of individuals as well as species, but the earliest of the Tertiary series are as free from their remains as the most recent formation. There is no cause for this sudden extinction of a great group unless it was a climatic one, and even this is not indicated by any change in the vegetable life of the two periods.

Below is a list of the various genera of the Dinosaurs arranged to show their systematic and time relations.

	Triassic	Jurassic	Cretaceous
THEROPODA	*Anchisaurus*	*Cœlurus*	*Lælaps*
	Zanclodon	*Ceratosaurus*	*Ornithomimus*
	Epicampodon	*Allosaurus*	*Megalosaurus*
	Massospondylus	*Labrosaurus*	
	Arctosaurus	*Creosaurus*	
	Tanystrophæus	*Megalosaurus*	
		Streptospondylus	
		Aristosuchus	
		Compsognathus	
		Hallopus	
SAUROPODA		*Brontosaurus*	
		Camarosaurus	
		Morosaurus	
		Apatosaurus	
		Cetiosaurus	
		Ornithopsis	
		Diplodocus	
		Titanosaurus	
PREDENTATA	*Dystrophæus*	*Stegosaurus*	*Agathaumus*
	Euscelosaurus	*Camptosaurus*	*Torosaurus*
		Laosaurus	*Claosaurus*
		Dryosaurus	*Hadrosaurus*
		Nanosaurus	
		Scelidosaurus	

E. C. CASE.

REFERENCES.

For the Theriodonta.

Osborn, H. F. A Great Naturalist. Century Magazine, November 1897.

Osborn, H. F. Origin of the Mammalia. Am. Nat., May 1898.

Lydekker, R. Catalogue of the Fossil Reptilia and Amphibia of the British Museum. Vol. IV, London 1890.

For the Dinosaurs.

Marsh, O. C. The Dinosaurs of North America. Sixteenth Ann. Rpt. of the Director of the U. S. Geol. Surv. (Contains a large number of illustrations of the various genera and a summary of the author's writings on the subject in the pages of the Am. Jour. of Sc.)

Baur, G. Remarks on the Reptiles Generally called Dinosauria. Am. Nat., May 1891.

Ballou, W. H. Strange Creatures of the Past. Century Magazine, November 1897. (Contains many good illustrations of Dinosaurs.)

EDITORIAL.

THE fiftieth anniversary of the American Association for the Advancement of Science was held at Boston, August 22 to 27. The total enrolled attendance was 903, new members 273. The number of papers read before the Geological Section was 29; before the Geological Society 19; before the National Geographic Society 8; making the total of geologic and geographic papers 55.

The titles of the papers were as follows:

VICE PRESIDENTIAL ADDRESS.

Glacial Geology in America. By Professor H. L. FAIRCHILD, Rochester, N. Y.

BEFORE THE GEOLOGICAL SOCIETY OF AMERICA.

1. Some Features of the Drift on Staten Island, N. Y. By ARTHUR HOLLICK, Columbia University, New York, N. Y.

2. Loess Deposits of Montana. By Professor N. S. SHALER, Cambridge, Mass.

3. Glacial Waters in the Finger Lake Region of New York. By Professor H. L. FAIRCHILD, Rochester, N. Y.

4. The Stratification of Glaciers, with lantern views. By H. F. REID, Baltimore, Md.

5. Evidences of Epeirogenic Movements Causing and Terminating the Ice Age. By WARREN UPHAM, St. Paul, Minn.

6. Clayey Bands of the Glacial Delta of the Cuyahoga River at Cleveland, O., compared with those in the Implement-bearing Deposits of the Glacial Delta at Trenton, N. J., with lantern views. By Professor G. FREDERICK WRIGHT, Oberlin, O.

7. The Middle Coal Measures of the Western Interior Coal Field. By H. FOSTER BAIN and A. T. LEONARD, Des Moines, Ia.

8. The Principal Missourian Section. By CHARLES R. KEYES, Des Moines, Ia.

9. Tourmaline and Tourmaline Schists from Belcher Hill, Jefferson county, Colo. By HORACE B. PATTON, Golden, Colo.

10. Magmatic Differentiation in the Rocks of the Copper-bearing Series. By ALFRED C. LANE, Houghton, Mich.

11. The Volume Relations of Original and Secondary Minerals in Rocks. By Professor CHARLES R. VAN HISE, Madison, Wis.

12. Note on a Method of Stream Capture. By ALFRED C. LANE, Houghton, Mich.

13. The Development of the Ohio River. By Professor WILLIAM G. TIGHT, Granville, O.

14. Classification of Coastal Forms. By F. P. GULLIVER, Southboro, Mass.

15. Dissection of the Ural Mountains, with lantern slides. By F. P. GULLIVER.

16. Note on Monadnock. By F. P. GULLIVER.

17. Spacing of Rivers with Reference to the Hypothesis of Base Leveling. By Professor N. S. SHALER, Cambridge, Mass.

18. The Continental Divide in Nicaragua. By C. WILLARD HAYES, Washington, D. C.

BEFORE THE GEOLOGICAL SECTION OF A. A. A. S.

1. Outline Map of the Geology of Southern New England. By Professor B. K. EMERSON, Amherst, Mass.

2. Basins in Glacial Lake Deltas. By Professor H. L. FAIRCHILD, Rochester, N. Y.

3. An Exhibition of the Rare Gems and Minerals of Mt. Mica. By Dr. A. C. HAMLIN, Bangor, Me.

4. The Hudson River Lobe of the Laurentide Ice-sheet. By Professor C. H. HITCHCOCK, Hanover, N. H.

5. The Age of the Amboy Clay Series as Indicated by its Flora. By Professor ARTHUR HOLLICK, Columbia University, New York, N. Y.

6. Some Feldspars in Serpentine, Southeastern Pennsylvania. By Professor T. C. HOPKINS, State College, Pa.

7. The Region of the Causses in Southern France, with maps and stereopticon views. By Dr. HORACE C. HOVEY, Newburyport, Mass.

8. The Washington Limestone in Vermont. By Professor C. H. RICHARDSON, Hanover, N. H.

9. Fluctuations of North American Glaciation shown by Interglacial Soils and Fossiliferous Deposits. By WARREN UPHAM, St. Paul, Minn.

10. Time of Erosion of the Upper Mississippi, Minnesota, and St. Croix Valleys. By WARREN UPHAM.

11. Supposed "Corduroy Road" of Late Glacial Age at Amboy, O. By Professor G. FREDERICK WRIGHT, Oberlin, O.

12. Changes in the Drainage System in the Vicinity of Lake Ontario during the Glacial Period. By Dr. M. A. VEEDER, Lyons, N. Y.

13. Recent Severe Seismic Movements in Nicaragua. By JOHN CRAWFORD, Managua, Nicaragua.

14. Another Episode in the History of Niagara River. By J. W. SPENCER, Washington, D. C.

15. The Age of Niagara Falls as Indicated by the Erosion at the Mouth of the Gorge. By Professor G. FREDERICK WRIGHT, Oberlin, O.

16. A Recently Discovered Cave of Celestite Crystals at Put-in-Bay, O. By G. FREDERICK WRIGHT.

17. Geography and Resources of the Siberian Island of Sakhalin. By Professor BENJAMIN HOWARD, London, Eng.

18. Evidence of Recent Great Elevation of New England. By J. W. SPENCER, Washington, D. C.

19. The Oldest Palæozoic Fauna. By G. F. MATTHEW, St. John, N. B.

20. The Oldest Known Rock. By Professor N. H. WINCHELL, Minneapolis, Minn.

21. The Origin of the Archæan Igneous Rocks. By Professor N. H. WINCHELL.

22. Joints in Rocks. By Professor C. R. VAN HISE, Madison, Wis.

23. Notes on Some European Museums. By Dr. E. O. HOVEY, New York, N. Y.

24. History of the Blue Hills Complex. By Professor W. O. CROSBY, Boston, Mass.

25. Palæontology of the Cambrian Terranes of the Boston Basin. By AMADEUS W. GRABAU, Boston, Mass.

26. Diamonds in Meteorites. By Mrs. E. M. SOUVIELLE, Jacksonville, Fla.

27. The Periodic Variations of Glaciers. By Professor HARRY F. REID, Baltimore, Md.

28. Note on the Occurrence of Tourmalines in Canada. By C. R. ORCUTT, San Diego, Cal.

29. The Agassiz Geological Explorations in the West Indies. By ROBERT T. HILL, Washington, D. C.

BEFORE THE NATIONAL GEOGRAPHIC SOCIETY.

1. The Venezuela-British-Guiana Boundary Dispute. By Dr. MARCUS BAKER, Washington, D. C.

2. Considerations Governing Recent Movements of Population. By JOHN HYDE, Washington, D. C.

3. Some New Lines of Work in Government Forestry. By GIFFORD PINCHOT, Washington, D. C.

4. The Development of the United States. By W J McGEE, Washington, D. C.

5. Atlantic Estuarine Tides. By M. S. W. JEFFERSON.

6. The Forestry Conditions of Washington State. By HENRY GANNETT, Washington, D. C.

7. The Five Civilized Tribes and the Topographic Survey of Indian Territory. By CHARLES H. FITCH, Washington, D. C.

8. Bitter Root Forest Reserve. By RICHARD U. GOODE, Washington, D. C.

The foregoing has been kindly furnished by Mr. Warren Upham, secretary of Section E, A. A. A. S.

***

GEOLOGISTS visiting the exposition at Omaha, and teachers everywhere, will find particularly valuable the topographic map of Omaha and vicinity, published by the United States Geological Survey and gratuitously distributed in the Mines and Mining building. The map bears the date of June 1898, and is an example of the excellence of the maps now being made. The main features are the Missouri River bottom land and valley, and the loess topography. The former is a most characteristic bit of river work. The cut-off lakes, the great bends of the river, the sharp bluffs where the stream impinges against the bank, and other features are shown so clearly as to make the map especially valuable in the class, room. The apparent similarity in width of the Platte and the Missouri rivers and the dissimilarity in their valleys, will likewise call forth questions.

It is, however, the loess topography which is most interesting, since within the limits of the quadrangle there is an excellent example of the contrast between the wind-shaped loess near, and the water deposited away from, the vicinity of the stream. On the west side of the river, in Omaha and near it, the map shows open contour, gentle slopes, and obvious erosion topography and a rectangular system of roads. The hills rise easily to 1200 or 1250 feet A. T. Immediately across the river the contours are close, the slopes sharp, the roads follow streams and ridges and disregard land lines, and the hills rise abruptly to 1300 or 1350 feet, A. T. A very characteristic feature, well shown on the map, is the large number of small detached peaks. Another is the interference

with the drainage, as for example in the case of Mosquito Creek. This stream, whose valley is followed by the Chicago, Rock Island and Pacific, and the Chicago, Milwaukee, and St. Paul railways, has a quite well developed flood plain and a broad, open valley in its upper portion. As it comes within the influence of the river loess, the valley is choked and becomes a mere narrow defile. This and the other features mentioned are not exceptional, but are found at quite distinct points along the Missouri,[1] and are of considerable significance in the matter of genesis of the loess. There are numerous other items of interest relative to the map, but sufficient has perhaps been said to call attention to its value. H. F. B.

[1] Geology Plymouth county, Iowa Geol. Surv., Vol. VIII, 1898, pp. 324–332.

Reviews.

STRATIGRAPHY OF THE SOUTHERN OZARKS.

Thickness of the Palæozoic Sediments in Arkansas. By John C. Branner. Am. Jour. Sci., (4), Vol. II, pp. 229-236, 1896.

Batesville Sandstone of Arkansas. By Stuart Weller. Trans. New York Acad. Sci., Vol. XVI, pp. 251-282, 1897.

Marine Fossils from the Coal Measures of Arkansas. By James Perrin Smith. Proc. American Philos. Soc., Vol. XXXV, pp. 213–273, 1897.

Geological Reconnaissance of the Coal Fields of the Indian Territory. By Noah Fields Drake. Proc. American Philos. Soc., Vol. XXXVI, pp. 326-419, 1898.

A decade ago one of our most distinguished writers on geology, commenting upon the progress of geological investigation in this country, drew special attention to the mountainous region of the central Mississippi basin by making the startling statement that that part of our national domain about which least was known geologically was not in the rugged ridges of the Appalachians nor in the great cordilleras of the Far West, but in the very heart of the American continent, in a district where mining had long been carried on — in the Ozark region. Surprising as was the statement it was literally true. Up to that time there had been practically nothing on the geology of this region published. There was no place to which one could turn for information regarding the geology of a tract of more than 100,000 square miles.

Singularly enough, as if anticipating the full force of the remark alluded to, and before the paragraphs had left the press, the states of Arkansas and Missouri established geological surveys the express purposes of which were to solve this very problem. As the result of these official activities there have been published by the two states mentioned

upwards of twenty-five large volumes, all of which are devoted, wholly or in part, to the geology of the Ozarks.

Growing out of this official work, either directly or indirectly, there have appeared from time to time other contributions to a geological knowledge of the region. The Arkansas geologists have been especially active in setting forth information of the greatest value concerning the *terra incognita* of only ten years ago. Branner, Winslow, Penrose, Hopkins, J. F. and H. S. Williams, and Griswold have all given us geological accounts of great interest. The results of their work have been most acceptable. An outgrowth of this same work has been to induce others to take up attractive lines of investigation thus pointed out. At intervals there have been given short sketches that fill in important gaps.

Isolated from all localities where similar rock successions were already carefully studied and were well known, the workers in Arkansas were obliged to set up a geological rock classification of their own. The sequence of terranes could be correlated with those of well-known regions only in the most general way. Much has been done of late to clear up the existing uncertainty of stratigraphic equivalency. The early Palæozoic rocks still resist all attempts of detailed classification and correlation. The Carboniferous has yielded more gracefully. With the latest contribution, by Drake, the last link binding the stratigraphy of the southern region to the northern has been forged.

The "Thickness of the Palæozoic Sediments in Arkansas," by Professor Branner, may be taken as a concise summary of the results of the Arkansas geological survey regarding the sequence and development of the older rocks of the southern Ozarks. The article is accompanied by a small but excellent general geological map of the state, and gives a classification of the formations recognized, and their observed thicknesses. The enormous estimated thickness of the Coal Measures is especially noteworthy. These figures come somewhat in the nature of a surprise, manifestly to the author also, for he takes particular pains to present clearly the detailed evidence upon which he has reached his conclusions. He says: "There is, of course, nothing remarkable about the thickness of any of the Arkansas sediments except in the case of the Lower Coal Measures. So far as I can learn the thickness of the Carboniferous rocks in this section is greater than that of the sediments of the same age in other parts of the country or of the world."

The general section of the Palæozoic sediments is as follows:

Coal Measures or Pennsylvanian	Upper Coal M.	Poteau beds Productive beds	3500 1800
	Lower Coal M.	Barren beds	18480
	"Millstone grit"	- - - - - - - -	500
Lower Carboniferous, or Mississippian	Chester, St. Louis, Warsaw	Boston group	780
	Keokuk-Burlington	Batesville sandstone Fayetteville shale Wyman sandstone Boone chert	200 300 10 370
Devonian?		Sylamore sandstone Eureka shale	40 50
Upper Silurian		St. Clair marble	155
Lower Silurian		Izard limestone Underlying beds	285 1750
			28220

The "Marine Fossils from the Coal Measures of Arkansas," by Dr. Smith, is largely a description of species, with comments upon their biologic relationships. Nevertheless, in the introductory portion, the stratigraphy is considered, and the conclusions reached concerning the position of the beds in the general geological column, as thought to be indicated by the fossil evidence, are set forth.

A table is given correlating the Arkansas strata with the Carboniferous deposits of China, India, Russia, South America, and other parts of the world. Done in such a broad way, it is hard to see just what force any extended discussion of this kind can have. Such faunal comparisons are, in general, of great interest in a biological way, and evidence a wide acquaintance with palæontological literature, but, from a geological standpoint, they have, with no reflection on Dr. Smith's efforts, small stratigraphic value. A detailed parallelism with its nearest related areas of Coal Measures, which is the great desideratum to all those at all interested in the geology of the region, and

which appears to have been, in starting out, the main object of the memoir, is the very phase that all would have desired to have discussed more fully. This, however, should not be expected, perhaps, since it pertains more particularly to the purely geological side of the question, and the paper lays most stress on the biologic aspects.

The account of the fossils is a welcome addition to our knowledge of the distribution of the Carboniferous organisms in the Mississippi province. While the list may appear meager, it must be remembered that heretofore only an occasional or straggling form was known from the region. Twenty-one localities yielded fossils. There are represented forty-eight genera and ninety species, some of which are not specifically identified. The "fauna is a poor one, such as one would expect to wander in from deeper waters whenever a slight subsidence made shallow waters a little more habitable. The faunas could not become well established, because the conditions soon reverted to their old state, and the inhabitants of the seas were forced to migrate or be exterminated."

In comparing the fauna with its nearest ally, in Kansas and Nebraska, the conclusion is reached that "there is not sufficient reason for classing the Poteau Mountain beds with the Permian, but their fauna, as well as stratigraphic position, place them very high in the Coal Measures, since they are like the fauna and position of the Mississippi Valley Upper Coal Measures."

The "Batesville Sandstone of Arkansas," by Mr. Weller, treats of the Lower Carboniferous of the northern part of the state. While the greater part of the paper is devoted to the description of fossils, the brief account of the stratigraphy and correlation features is the most important that has yet appeared on the subject. The comparison of the general section of the Lower Carboniferous in Arkansas with that of the typical localities along the Mississippi River shows that the two are essentially identical.

The "Batesville sandstone has the same stratigraphic position in the Batesville section which the Aux Vases sandstone occupies in the typical section, and the lithological characters of the two formations are similar. No fossils have as yet been found in the Aux Vases sandstone, but if a fauna were found a mingling of St. Louis and Kaskaskia species, such as are present in the Batesville sandstone fauna, would be looked for."

The parallelism of the Arkansas section of the Lower Carbonifer-

ous, or Mississippian series, with the one long known farther northward, is as follows:

Typical Mississippi Section	Arkansas Section
Kaskaskia limestone	Boston group
Aux Vases sandstone	Batesville sandstone
St. Louis limestone	Spring Creek limestone
Augusta limestones	Boone chert
Kinderhook beds	St. Joe marble
	Sylamore sandstone

According to this arrangement the former lines of division in the Arkansas formations will have to be modified considerably. The Kinderhook portion will doubtless need further revision in northern Arkansas.

A "Geological Reconnaissance of the Coal Fields of Indian Territory," by Dr. Drake, connects the Arkansas work with that of Kansas and Missouri. For the first time we are able to understand what relationships the subdivisions that were adopted by the Arkansas geologists, for the Coal Measures, have to those recognized in other parts of the interior province. The sketch-map accompanying the memoir gives the distribution of the formations; and a number of sections still farther elucidate the structure of the region.

A small crystalline area, the Spavinaw granite, discovered by Owen forty years ago, is found to be a dike, fifty feet wide, breaking through the crest of a low anticline of Silurian limestone. As, however, the overlying Lower Carboniferous in the bluffs a few yards away is also tilted in the same way as the Silurian strata, the age of the dike is regarded as post-Carboniferous. Since Owen mentioned the occurrence nothing further has been made known concerning this granite until the recent visit. The results of this examination are important, as they set to rest much speculation. As the granite must have been intruded under a considerable weight of superincumbent strata, it is somewhat surprising that all traces of metamorphic action should have escaped notice. The presence of the epidote would indicate that contact phenomena should be present, at least, in some slight degree.

The Silurian rocks appear only in a few limited areas in the extreme eastern part of the territory. All of these localities are north of the Arkansas River. Areas known to exist in the southern portion of the territory are omitted.

The Lower Carboniferous is well represented, the western boundary being approximately the Neosho River. The beds are continuous with those of northwestern Arkansas and southwest Missouri. The subdivisions recognized are the Eureka shale, Boone chert, Fayetteville shale, Batesville sandstone and the Boston group.

The rest of the Carboniferous is subdivided into Lower Coal Measures, Upper Coal Measures (with two groups, the Cavaniol or coal producing, and the Poteau or barren) and Permian.

The remainder of the paper is taken up with lists of fossils, some descriptions of new species, and a short economic chapter.

The restriction of the term Ozark to the northern part of the uplifted region of Missouri and Arkansas is noticeable. It is, no doubt, convenient to distinguish the northern, slightly folded part from the southern, trans-Arkansas portion, and to designate the latter the Ouachita region. The latter term will be generally used. This should not, however, be to the exclusion of some other name for the whole of the elevated area. The use of Ozark in the restricted sense as has been done, without giving any geographical reason, at once arbitrarily subdivides the region. The uplift, or dome, is believed to be a great geographic unit, having a definite history that covers the Ouachita district the same as the more northern area. From a geographic standpoint the close folding has no especial influence in the general development nor in determining its broad physiographic nature.

If the two districts are really distinct in their present aspects, when viewed from the genetic and geographic points of vantage, it should be shown that their development is in no way connected, that the history of each has been different, that their present physiognomies are of diverse origin. This has not been done as yet; and no attempt appears ever to have been made in this direction.

On the other hand all the published materials and the known facts seem to point to a very different course of events. After the Carboniferous the region between the Missouri and Red rivers was apparently subjected to orogenic movements—intense and local in the south, moderate and regional in the north. The whole region was then planed down during the Cretaceous or Tertiary, perhaps, practically base-leveled, so as to form part of the great peneplain of the Mississippi valley. The closely folded area appears to have been planed off in the same way as the broad flexures. Subsequent elevation of the

peneplained surface in a broad dome, higher in the south than in the north, set to work again the forces of degradation. In the south greater elevation, highly tilted strata, and soft beds alternating with hard, of the Coal Measures, gave rise to great contrasts of relief. In the north, with less height, gently inclined strata and resistant dolomites and limestones very different relief effects were produced.

The mountains of the Ouachita district appear to have tolerable even tops. In the novaculate region, in the extreme south, where the rocks are very hard, the mountains have only half the height of those a little farther north, but made up of softer beds, or soft layers alternating with harder ones. The great Arkansas River has cut its broad valley through soft shales of the Coal Measures. Everything goes to show that the present aspect of the whole elevated region is the result of one grand recent bowing up.

The correlations of the Coal Measures made by Dr. Drake are of great interest. In the June issue of this journal reasons were given for believing that nearly the whole of the enormous thickness of the Coal Measures of Arkansas was the equivalent of only the Lower Coal Measures of Missouri and Kansas—the Des Moines series. Dr. Drake's notes and map appear to afford conclusive proofs of this view. His great basal sandstone, "Lower Coal Measures," and the productive group (Cavaniol) taken together would appear to represent approximately the Des Moines series. I say approximately, for it is not yet quite certain just what is the upper limiting horizon of the "Cavaniol." On his map, where the western boundary of the latter leaves the territory northward, it meets the lower member of the Bethany limestone—the basal stratum of the Missourian series, and Upper Coal Measures of the western interior coal basin. The presence of marked escarpments at various places beyond this western boundary line are also taken as indications of the southern extension of the Kansas Missourian.

In like manner the Poteau group seems to be the equivalent of that part of the Missourian series of Kansas, below the Wabaunsee shales. Possibly its upper limiting horizon is even lower.

We are certainly deeply indebted to Dr. Branner and his associates for a set of contributions of much more than passing general interest and of inestimable local value.

C. R. KEYES.

The Newark System or Red Sandstone Belt (of New Jersey). By HENRY B. KÜMMEL. Annual Report of the State Geologist of New Jersey for 1897, pp. 25–159. Trenton, N. J.

In the corresponding report for 1896 Dr. Kümmel presented a brief report on the Newark system of the western part of New Jersey. He has now extended his work so as to cover the whole of the area of the system within the state, and the present report embodies the results of his fuller studies. As indicated in an earlier number of this JOURNAL, Dr. Kümmel finds the Newark system divisible into three series, the basis for subdivision being lithological, not palæontological. These divisions, commencing below, are (1) the Stockton series, the characteristic beds of which are arkose sandstones and conglomerates; (2) the Lockatong series, the characteristic beds of which are black shales, dark, massive argillites, and gray and green flagstones; and (3) the Brunswick series, consisting primarily of red shale and sandstone. Maps are presented showing the distribution of these several divisions. As a result of the profound faults affecting the western part of the system, the several series do not appear at the surface in single, continuous belts, but are repeated. The disposition of the outcrops is still further complicated by the folding which the beds of the system have suffered. In the eastern part of the state the Lockatong series does not appear, but the Stockton series is found in limited areas on both sides of the Palisade ridge.

One of the interesting facies of the system is the conglomerate which occurs along its northwest border, at and near its junction with the pre-Mesozoic terranes. This conglomeratic phase of the system assumes different aspects at different points. It is now made up chiefly of limestone, now of gneiss; and now of quartzite; but the significant point in the relations of these several phases of conglomerate is the fact that the larger areas of calcareous and quartzite conglomerates do not abut against older formations of limestone and quartzite, but against gneiss instead. The conglomerates are clearly shore deposits, and it is therefore inferred that the conglomerate beds were not derived chiefly from the older formations against which they now lie. It is believed that faulting along the contact of the Triassic system with the older formations is responsible for the lack of correspondence between most of the conglomerates and the formations against which they abut.

Another point of interest and significance is found in the fact that the conglomerates do not occupy a distinct horizon, but that each of the three series in turn becomes conglomeratic as the border of the system is approached. Incidentally it may be inferred that the northwestern extension of the system was never much greater than now, since the shore phase of each series is represented along the present border.

The relations of the igneous rocks of the system also receive much more systematic discussion than in any previous publication. Several small areas of igneous rocks (dikes) heretofore unmapped have been located. While the previous conclusions as to the intrusive character of some of the trap sheets and the extrusive character of others are confirmed, the evidence on which these conclusions rest is so fully detailed, and is in itself so decisive, that further discussion of this point is not likely to arise.

Many of the principal structural features of the Newark system have long been known, but no previous student of these formations has worked out the details of the structure with anything like the fullness shown by the present report. The general monoclinal structure of the system (strike N. 30° to 50° E, and dip 13° or 15° to the northwest) is found to be affected by several broad, gentle flexures, and by a few sharply marked folds, especially in the vicinity of the intrusive sheets of trap and along the greater fault lines. The positions of these flexures are given and their effects on the topography, where beds of unequal resistance outcrop, are pointed out. Even among the gentle folds of the system the axes of flexure sometimes depart from horizontality because of still gentler cross-folds, showing that the forces which deformed the beds were not confined to one direction.

The beds of the Triassic system have long been known to be faulted, but not until now have these faults been worked out in detail. Of the two major faults, one (the Flemington fault) was known before Dr. Kümmel's studies began, while the other (the Hopewell fault) was discovered by him. Both these faults have a throw of several thousand feet, and each causes the repetition of the outcrop of each of the three series of the system. Besides these two principal faults, displacements are believed to exist along the northwest border of the system at more than one point.

Of minor faults there are many. Something like fifty are described, and many figures are given showing in a graphic way the evidence on

which their existence is known. The throw of these minor faults varies from a few feet to several hundred. The faults enumerated are more frequent in the trap than in the shale and sandstone. Since faults are much more easily detected where they affect the trap, owing to the fact that this formation has come to assume the form of ridges since the faulting, it is inferred that minor faults affecting the more homogeneous portions of the sedimentary part of the system may have escaped observation.

But for the faults, the determination of the thickness of the system would be an easy matter. Allowance can be made for the faults which are known, but there is no way of taking quantitative account of those which have not been discovered. Impressed with the fact that there may be many undiscovered faults of slight extent in the homogeneous shales and sandstones, Dr. Kümmel has revised his estimate of the thickness of the system, and now gives the following figures:

Brunswick series, - - - - -	6,000 to 8,000
Lockatong series, - - - - -	3,500 to 3,600
Stockton series, - - - - -	2,300 to 3,100
	11,800 to 14,700

The thicknesses of the principal sheets of trap are also given, the thickest being less than one thousand feet. A brief discussion of the conditions of the origin of the system is followed by a résumé of its economic resources.

The report, as a whole, presents in excellent form the results of a piece of work which is not likely to need revision. It is a matter of congratulation that Dr. Kümmel has this year been able to extend his studies over the Triassic area of New York.

R. D. S.

The Geological History of the Isthmus of Panama and Portions of Costa Rica. By ROBERT T. HILL, Bulletin of the Museum of Comparative Zoölogy at Harvard College, Vol. XXVIII, No. 5, pp. 151–285. Nineteen plates. Cambridge, 1898.

The results embodied in this report are based on a reconnaissance made by the author for Alexander Agassiz in 1895. In spite of the fact that the region concerned was only reconnoitered, the report adds

much to our knowledge of tropical America. Some of the geographic features which characterize the region have been briefly described by the author in earlier publications, but the geological results of the reconnaissance have not before been published. So far as practicable, Mr. Hill's conclusions are stated in his own words.

In the first place, emphasis is laid upon the independence of the North American, Central American, and South American orogenic systems. The Cordilleran system of North America ends in Mexico, a little south of its capital city. The Andean system of South America has its northern terminus east of the Isthmus of Panama, and has no genetic connection with the mountain ranges of the north coast of South America. If the Cordilleran and Andean systems were extended southward and northward respectively, they would pass each other in parallel lines hundreds of miles apart. The extension of the Andean system would lie not only east of the Cordilleran, but even east of the Appalachians, while the extension of the Cordilleran system would lie in the Pacific, far west of the South American coast.

Between the termini of these orogenic systems, with a trend at right angles to both, lies a third system, called the Antillean. It is this system of mountains which has determined the major topographic features of the Antillean region. The system includes the east-west ranges of the north coast of South America, those of the Isthmus, Central America, southern Mexico, and the Great Antilles. In the Caribbean sea, two east-west submarine ridges, separated by the Bartlett Deep, show that the east-west trend of the crustal corrugations of this region affect the sea bottom as well as the land. Like the greater systems to the north and south, the Antillean system is composed of folded sedimentary rocks, plus volcanic intrusions and ejecta. While each of the major orogenic systems dominates a continental area, the Antillean system "constitutes a mountainous perimeter surrounding the depressed basin of the Caribbean."

The primary geographic features of that part of the continent dominated by the east-west system are 1°, a volcanic plateau near the Pacific coast along the western termini of the ranges of the Antillean system, and 2°, the lower but mountainous area facing the Caribbean, consisting of folded beds of sedimentary rock, associated with igneous. To the north, the western termini of the Antillean ranges are buried by the volcanic rocks, but on the Pacific side of Panama, the Antillean ranges continue across the land area.

The surface of Panama is described as consisting of irregularly rounded mountains and hills, 200 to 1500 feet in height. Their topographic expression is uniform whatever the rock of which they are composed. Lack of systematic arrangement in their distribution is said to be one of their striking features, though an east-west trend is locally observable. Their form and arrangement are ascribed primarily to erosion.

"In common with the whole Central American region south of Yucatan, the Isthmus of Panama presents no such feature as a well-defined coastal plain like that bordering the eastern and southern margin of the United States. . . . . Such occasional levels as may be recognized on either coast are the products of the erosion of the greatly distorted sedimentaries and volcanic rocks. . . . . The Caribbean coast is generally marked by jagged and abrupt bluffs where the sea beats directly against the hills. The indentations are slight and far apart. The same may be said of the Pacific side."

The drainage of the Isthmus is defined as "ancient, mature and autogenous, consisting of deeply incised headwater ramifications drowned in their lower courses toward the sea." Although the drainage of the Isthmus is about equally divided between the two oceans, there is no well defined watershed separating the waters flowing into the Atlantic from those flowing into the Pacific.

The Isthmian region is now undergoing rapid erosion, the result of the excessive rainfall (154 inches in 1894), and of the activity of the waves of the oceans. The topography of the sea bottom on either side points to a former greater expansion of land, and therefore to the fact that the narrow neck of land is, and has been disappearing under the influence of the agencies mentioned. This conclusion is further borne out by the outlying islands, which, by their structure and relations, show themselves to be isolated remnants of the mainland.

Two detailed geological sections are given, one across the Isthmus from Colon to Panama, and the other across Costa Rica. In the Isthmian section, seven structural units are recognized. These are (1) the fringing coral reefs; (2) the coastal swamps of both coasts—elevated plains of sedimentation; (3) the Monkey Hill and Panama benches—elevated base-leveled plains; (4) the folded and disturbed Tertiaries which owe their positions to the series of post-Tertiary (post-Oligocene) orogenic foldings along the Caribbean side of a more ancient nucleal region; (5) the numerous protrusions of basic igneous rocks,

the age of which is not definitely known; (6) the sedimentary rhyolitic and andesitic tuffs, the Panama formation, older than the basic igneous formations; and (7) the granitic rocks, the oldest of the region. The sedimentary rocks of the section fall into three categories: (1) those of supposedly pre-Eocene age, occurring on both sides of the Isthmus; (2) the fossiliferous Tertiary beds of the Caribbean side, and (3) the Pleistocene beds deposited synchronously on both sides.

The rocks of the first of these three classes are so distorted and concealed by later igneous protrusions and deposits that little was learned of their relations. They are composed almost entirely of rhyolitic and andesitic material. The beds of the second class are referable, on the basis of their fossils, to the Eocene and Oligocene, corresponding approximately with the Tejon, Claiborne and Vicksburg formations of the United States. They are composed mainly of muddy sediments with more or less sand, glauconite and lignite. Limestone occurs at two horizons. It is to be specially noted that the Tertiary deposits of the Isthmian section end with the Oligocene (early Miocene), and there is nothing to indicate that sedimentation was in progress in the Isthmian region during the later Miocene and Pliocene epochs. The inference is that "the Isthmian land was of much larger area during these later epochs than in Eocene time or at present." The thickness of the Tertiary system is thought to be as much as 1000 feet, and possibly much more.

The igneous rocks of the Isthmian section consist of (1) granite in ranges having an east-west trend; (2) rhyolitic tuffs and pumice, igneous in origin, but sedimentary in arrangement; and (3) basic igneous rocks, occurring as intrusives, eruptives, tuffs, etc. The basic rocks are younger than the others, but are thought to have been in existence during the deposition of the later Eocene sediments. Other considerations prevent the reference of these rocks to an earlier period, and lead to the conclusion "that the most marked volcanic episode of the Isthmian region took place during the later Eocene epoch." It is thought that there are also late Tertiary syenitic intrusives, which "now form the core of great mountainous protuberances."

Throughout the Isthmian region, the surface red clays conceal all the formations. They are believed to be largely the residuum of rock decay. The extent of this decay is said to be "enormous, extending often to a depth of over 100, and seldom less than fifty feet."

In the Costa Rican sections the principal geological features may

likewise be grouped in seven categories. There are (1) the foundation rocks of ancient quartzites, serpentines, jadeite, and granite, probably pre-Cretaceous; (2) limestones, which are believed to be Cretaceous; (3) basic igneous rocks of Eocene, and possibly of late Miocene age; these rocks conceal most of the older formations and are, in turn, largely buried beneath later volcanics; (4) the marine Tertiary sediments, Eocene to Pliocene inclusive, of the Caribbean side; the early beds of this group are extensively disturbed, elevated and broken through by igneous protrusions; against these deformed and eroded strata the Pliocene beds rest unconformably; (5) a line of volcanoes surmounting the Sierras; (6) the Pleistocene sediments of the coasts, and (7) the "bolsons," base-leveled plains, benches, canyons and other topographic features.

In this section the "bowlder clays" of tropical America are encountered. The study of some of the craters of the region throws some light on the origin of these clays. From the craters fine material, such as scoriaceous ash, is thrown in quantity. With these fine products are also many large bowlders of black, massive igneous rock. Subjected to prolonged decay, this mixture of fine and coarse materials would, it is affirmed, leave a residuum identical in appearance with the bowlder clays. The glacial hypothesis, as an explanation of this formation, is regarded as untenable.

On the slopes of one of the mountains, Irazu, between the altitudes of 7000 and 9500 feet, there is found a fine pulverulent yellow dust, which is "in every way identical in lithological appearance and behavior with the loess deposits . . . . of the Missouri and Ohio." This formation is composed of the minerals common to the lavas of the region, but its mode of accumulation is not discussed.

Comparing the two sections, it is stated that "the Panama section is across an old land now nearly graded to the sea, where vulcanism has been quiescent since the Tertiary time," while "the Costa Rican section presents us a view of an ever-growing land where volcanoes have continued to pile their débris from Cretaceous time to the present."

Under the caption, "The Union of the Continents and the Problems of the Straits," the general relations of the Central American and Isthmian regions are discussed. The meager knowledge at hand indicates that "previous to the vast accumulations of more modern igneous and sedimentary rocks of Tertiary and post-Tertiary age, a foundation of granitic rocks, occurring in east and west arrangement,

existed in the South Isthmian and Central American region, extending in echelon arrangement from the longitude of Trinidad through forty degrees to near that of Acapulco, Mexico, directly across the path of the main continental trends." Palæozoic rocks are known with certainty, in the general area under consideration, in but one region, viz., in the Republic of Guatemala, and the adjacent Mexican border region. Their surface development is certainly very meager south of the United States. Triassic rocks, likewise meager south of the United States, also occur in Guatemala, but Jurassic beds are not known at any point in Central America. Cretaceous strata are much more widely distributed in tropical America; but while they cover most of Mexico, it is doubtful if the two oceans were at any time connected across this country in the Cretaceous period. This conclusion is based on palæontological evidence.

As to the Tertiary beds, the facts now in hand "indicate the existence of a continuous littoral of older Tertiary sediments around the Caribbean side of the tropical American region, and incidentally a preëxisting land which they bordered. . . . . These older Tertiary beds . . . . probably belong to the continuous series of sediments of the Eocene and Oligocene epochs. . . . . The Pliocene formations have not been clearly distinguished . . . . from the Pleistocene. There is an intermittent fringe of alleged Pliocene deposits around the Caribbean coast, unconformably deposited against the older continental mass. . . . . We may infer from the relatively slight area of the marginal development of rocks of this period, and their absence in the elevated or folded regions away from or much above the coast line, that it was just prior to the Pliocene period or during its earlier days that the Caribbean coast line, as a result of the tremendous orogenic processes by which the earlier Tertiary rocks were deformed, practically assumed the slope as we now know it."

In elaboration of this point, it is further stated that the early Tertiary strata have "since their deposition been elevated above the sea to great heights by folding on the Caribbean side of the old Isthmian protaxis until they stand 3000 feet in Guatemala, 5000 in Talamanca, 300 near Colon, and 500 at Cartagena. . . . . In Hayti, Cuba, and Jamaica, these plicated, Cretaceous, and early Tertiary rocks are found at altitudes exceeding 10,300, 8000, and 7250 feet, respectively, above the ocean. The east and west strike both of the Tertiaries and of the basic igneous rocks along the northernmost coast of South America

and in the Great Antilles is directly in harmony with the east and west trend of the same phenomena upon the mainland, and we cannot escape the conclusion that they are the product of the same great orogenic revolution, the age of which was mid-Tertiary, for rocks of early and late Eocene (and Oligocene) age everywhere, as exposed along the Caribbean coast, and in the Great Antilles, are folded by these mountain-making processes, while the Pliocene and Pleistocene are more horizontally laid down against the seaward margin of the mountain masses."

It is worth noting that the great orogenic movements of this region, dating from the later part of the Miocene, are in harmony with the great disturbances which took place in several continents at about the same time. They furnish a significant commentary on the infelicity of the current grouping of the Miocene and Pliocene under the common name Neocene. Nearly everywhere outside the regions of glaciation, the Pliocene and Pleistocene are more closely associated than the Miocene and Pliocene. The above use of the term Neocene makes this *period name* cover an interval of time in the midst of which occurred one of the most profound physical revolutions to which the earth's crust has been subject. For such use of the term there is but one analogy in the nomenclature of post-Algonkian time, namely, that of the use of the term Silurian, to cover all beds between the Cambrian and Devonian, although in the midst of this division occurs the greatest break, both stratigraphic and palæontologic, in the whole Palæozoic. The other physical revolutions comparable to that which took place at the close of the Miocene mark not simply the close of periods, but of eras.

In post-Miocene time, or perhaps accompanying the orogenic movements referred to, there was epeirogenic uplift and erosion, followed by moderate subsidence, and still later by uplift of slight extent, converting the shallow margin of the sea into low-lying coast lands.

The igneous rocks of the region appear to have a wide range in age. The age of the granitic mountains of east-west trend is not known, but they seem to be mainly pre-Tertiary, and probably pre-Cretaceous. Some of them may be much older. The later igneous rocks of the region seem to date in part from the later part of the Cretaceous period. Here belong the rhyolitic tuffs of the Panama formation which is believed to be pre-Tertiary. In the early Tertiary also there was great volcanic activity, but whether the vulcanism of the

close of the Cretaceous, with its accompanying disfiguration of topography, "was continuous to the present, or alternated with long periods of quiescence, cannot be answered." Thus volcanic activity accompanied the orogenic movements of Miocene time, giving "the most cataclysmic revolution of all geologic time and place."

Summarizing the evidence touching the union of the northern and southern continents, it is said that nothing is known of their relations in the Palæozoic; that land may have been continuous between them in the early Mesozoic; that it was probably so in the Cretaceous; and that in the Tertiary period only, in later geologic time, does the connection of the oceans across tropical America seem to have been possible. For their connection, even in this period, the evidence is much less conclusive than is commonly believed. For such connection "no stratigraphic proof has been discovered," and the physical character of the Tertiary sediments seems to be distinctly against any broad union. The only evidence pointing to their connections is palæontological, and even this is meager. In a single terrane of the Eocene, five species of mollusks on the Caribbean side of the Isthmus occur also in the Tejon Eocene of California. These species are held to indicate that in the Tejon epoch there was at least a shallow communication between the oceans, and that "to this epoch alone can the date of an interoceanic connection be assigned by direct palæontological evidence. . . . . All the authentic biologic and geologic evidences are entirely opposed to the possibility of a communication between the two oceans across the Isthmus or tropical American region in Pliocene or Pleistocene time." The statement of Upham, Spencer, and others, that marine Pleistocene fossils have been found at great heights on the Isthmus, is said to be erroneous.

R. D. S.

Recent Publications.

—Addison, Wm. L. T., B.A. On Crystal Formation of the Elements and their Allotropic Modifications, with a deduction of the Atomic forms therefrom. Toronto, Canada, 1898.

—Ailio, Julius. Über Strandbildungen des Litorinameeres auf der Insel Mantsinsaari. Bulletin de la Commission de la Finlande. No. 7. Helsingfors, April 1898.

—Bain, H. Foster. Geology of Decatur County. From Iowa Geological Survey, Sixth Annual Report, Vol. VIII, 1897. Des Moines, 1898.
Geology of Plymouth County. *Ibid.*

—Curtis, Geo. Carroll. A Model of Seacoast Characteristics. Journal of School Geography, Vol. I, No. 6, June 1889.

—Davis, W. M. The Equipment of a Geographical Laboratory. Reprinted from the Journal of School Geography, Vol. II, No. 5, May 1898.
Waves and Tides. *Ibid*, No. 4, April 1898.

—Chicago Academy of Sciences. The Mollusca of the Chicago Area. The Pelecypoda (Geological Notes). By Frank C. Baker. Bulletin No. III, Part I of the Natural History Survey, September 1, 1898.

—Derby, O. A. Monazite and Xenotime in European Rocks. Reprinted from the Mineralogical Magazine, Vol. XI, No. 53.
On the Accessory Elements of Itacolumite and the Secondary Enlargement of Tourmaline. Am. Jour. Sci., Vol. V, March 1898.

—Fairchild, Herman L. Glacial Geology in America. An Address before the Section of Geology and Geography, Amer. Association for the Advancement of Science, Boston Meeting, Fiftieth Anniversary, August 1898. Salem Press, Salem, Mass.

—Field Columbian Museum. Publication 28. Vol. II, No. 3. Ruins of Xkichmook, Yucatan. By Edward H. Thompson.

—Geikie, James. The Tundras and Steppes of Prehistoric Europe. Reprinted from the Scottish Geographical Magazine for June 1898. Edinburgh.

—Iowa Geological Survey. Six Annual Report, 1897, Vol. VIII. Samuel Calvin, State Geologist, Des Moines, Ia.

—Ordoñez, M. Ezequiel. Note sur les Gisements d'or du Mexique. Mexico, 1898.

—RICE, WILLIAM NORTH. Geology and Mineralogy. Reprinted from "The Smithsonian Institution, 1846–1896, the History of its First Half Century." City of Washington, 1897.

—State University of Iowa, Bulletin from the Laboratories of Natural History of. Vol. IV, No. 3. Iowa City, Ia., June 1898.

—United States Geological Survey.

Eighteenth Annual Report of the Director to the Secretary of the Interior, 1896–7. Charles D. Walcott, Director.

Map of Alaska, showing known Gold-Bearing Rocks, with Descriptive Text, containing Sketches of the Geography, Geology, and Gold Deposits and Routes to the Gold Fields. S. F. Emmons.

—VAN HISE, C. R. Metamorphism of Rocks and Rock Flowage. Bull. Geol. Soc. of America, Vol. IX, pp. 269–328. Pl. 19. Rochester, N. Y.

—WATSON, THOMAS L. Weathering of Diabase near Chatham, Va. From the American Geologist, Vol. XXII, August 1898.

—WILLISTON, S. W. The Sacrum of Morosaurus. Contributions from the Palæontological Laboratory, No. 33.

On the Skull of Xerobates (?) undata Cope. *Ibid.*, No. 32.